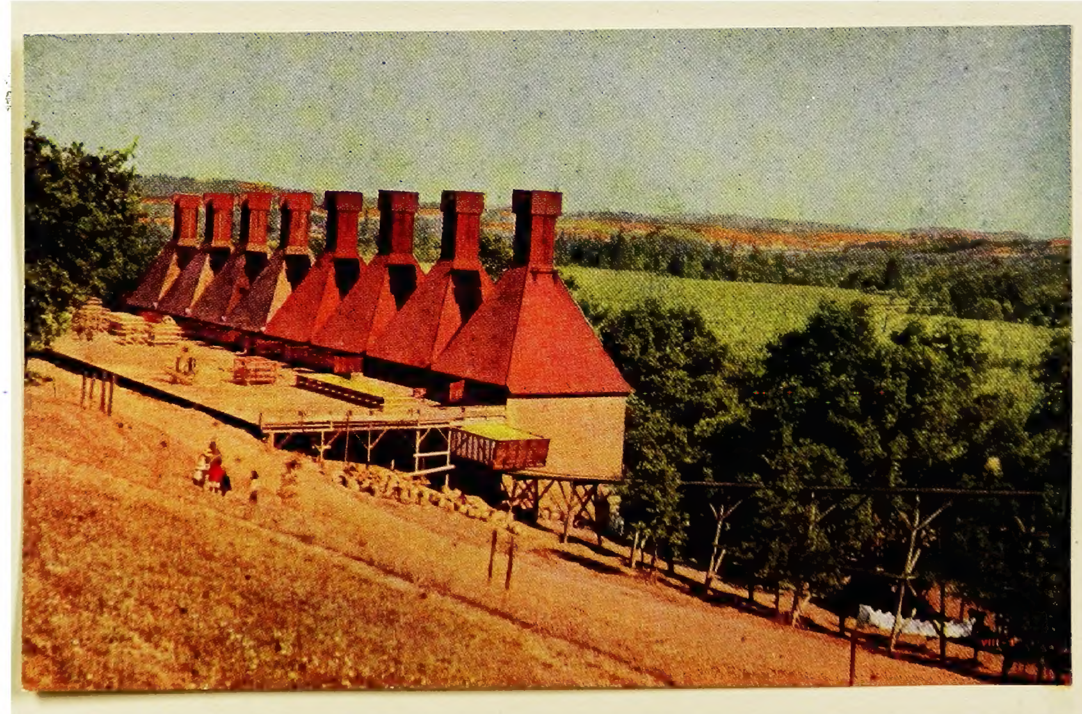
In the Hop Country

The curious buildings in the middle ground are typical houses for the curing of hops. A glimpse at the hop field itself is seen over the treetops. The hop industry is an important one in some portions of California, and in many other regions of the United States. Yet comparatively little has been done to develop the possibilities of the hop as a producer of larger quantities of the chemical for which it is prized.



LUTHER BURBANK

HIS METHODS AND DISCOVERIES AND THEIR PRACTICAL APPLICATION

PREPARED FROM
HIS ORIGINAL FIELD NOTES
COVERING MORE THAN 100,000 EXPERIMENTS
MADE DURING FORTY YEARS DEVOTED
TO PLANT IMPROVEMENT

WITH THE ASSISTANCE OF
The Luther Burbank Society
AND ITS
ENTIRE MEMBERSHIP

UNDER THE EDITORIAL DIRECTION OF
John Whitson and Robert John
AND
Henry Smith Williams, M. D., LL. D.

VOLUME VIII

ILLUSTRATED WITH
105 DIRECT COLOR PHOTOGRAPH PRINTS PRODUCED BY A
NEW PROCESS DEVISED AND PERFECTED FOR
USE IN THESE VOLUMES

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Volume VIII—By Chapters

Foreword to Volume VIII

Corn, Wheat, Oats, Barley and Hay are crops which receive attention in this volume, as well as the textile plants and those which yield useful substances to commerce and chemistry; also the complete story of the Cactus, which has often been hinted at, but never before told, is given here.

All of the work described in this volume is new, and the public, hitherto, has known but little of Mr. Burbank's efforts along these lines.

His work with corn, that already much improved crop, is in particular noteworthy. In addition to the many practical pointers on method, which Mr. Burbank outlines in this volume, there will also be found scores of suggestions for further plant improvement—concrete ideas which have come to Mr. Burbank in his work, but which he has not yet had time to carry out.

THE EDITORS.

A Section of Rainbow Corn Leaves

This curious and beautiful variation in the foliage of the familiar maize was brought about by Mr. Burbank through hybridization and careful selection; the original mutant with which he worked having been imported from Europe. Mr. Burbank is now endeavoring to combine these beautiful qualities of leaf with correspondingly attractive qualities of grain.

Corn—The King of America's Crops

Not Only Better Corn But A Better Stalk—And Why

THE potato, tobacco, and Indian corn or maize—these are the three great American contributions to the company of cultivated plants.

The potato and tobacco and bean have gone everywhere, but corn is still chiefly raised in the country of its nativity. It is extensively cultivated, however, far to the north of its original habitat. The great corn state now is Iowa, and the original home of the ancestors of the corn plant was the region of Southern Mexico and Central America.

In a recent year there were 1,144,500 acres of land in the United States given over to the cultivation of tobacco, and the crop raised amounted to 963,000,000 pounds. For potatoes 3,655,000 acres were utilized, raising a crop of 421,000,000 bushels. Wheat was raised on 18,663,000 acres, giving a crop of 330,000,000 bushels.

[Volume VIII—Chapter I]

This is an enormous acreage and a colossal output. Yet it seems almost insignificant in comparison with the record of corn. For to that crop 106,884,000 acres were devoted, and the crop harvested aggregated 3,125,000,000 bushels.

Nothing that could be added would better show the supremacy of King Corn than this citation of comparative statistics. A crop that tops the three billion bushel mark stands by itself among all the products of the cultivated acres of the world. Not only is it America's greatest crop; there is no crop of any other cereal or any single vegetable product whatever that equals this record anywhere in the world.

It is true that the corn crops of other nations are comparatively insignificant in contrast with the crops of small grains. But this is merely because corn demands peculiar conditions, notably a very hot summer, to bring its product to perfection. A goodly quantity of corn is exported; and the beef and pork that corn has produced are sent everywhere.

The Ancestor of King Corn

Among the most interesting experiments that I have performed in the development of corn, have been those that had to do with the primitive plants that were the progenitors of the present developed product.

A Typical Corn Stalk

This picture is shown to make clear the relations of pollen-bearing and ovule-bearing organs in the mechanism of the corn plant. The pollen, being borne in the tassel at the top, naturally sifts down, as carried by the wind, on the "silk" which constitutes the stigmas of the seed-bearing flower. It is obvious that the opposite arrangement of the two types of flowers would not have answered at all.

The plant from which Indian corn was unquestionably developed, or at all events, a very closely related form that has not been greatly modified from the primeval type, is a gigantic grass that still grows in Mexico and is a valuable forage plant. It is called *Reana luxurians,* or *Euchleana Mexicana.* Its familiar name is Teosinte.

This is a tall, sturdy plant, resembling corn as to its stem and stalk, but having a rachis like wheat or barley or rice that by comparison with the ear of the cultivated corn is insignificant.

In the wild teosinte each grain shells out readily like oats, wheat, or barley, and has an exceedingly hard, polished, chitenous covering, for protection against marauding birds and animals. The grains are arranged in two double opposite rows on a fragile rachis, like that of other grains such as rye, barley and rice; the cob of the developed corn being wholly a product of man, and being required to hold the numerous large, fat, nutritious kernels which it has been induced to produce through centuries of cultivation.

Teosinte, when brought under cultivation at the present time, after a few generations in the new and more favorable environment, like all other cultivated plants tends to vary. Like many of the half wild plants, teosinte has an inveterate tendency to sucker from the root.

Anyone who has suckered a field of corn on a hot June day will appreciate the importance of eliminating this wild habit of the teosinte, especially when grown for grain rather than for food. It must have taken centuries to eradicate this defect, as it is even yet more or less persistent in nearly all varieties of corn.

In kernel the teosinte most resembles, though not by any means very closely, our common varieties of pop corn; but with this great difference: only a pellicle protects the kernel in all our cultivated corn, while the tough, chitenous covering envelops the kernels of teosinte. But the resemblance of the plant itself to the corn plant leaves no question of their affinity, and the head of grain, notwithstanding its insignificant size, has individual kernels that are suggestive of diminutive kernels of corn.

If any doubt were entertained as to the relationship of this wild plant to the cultivated corn, this would be dispelled by hybridizing experiments, for the two cross readily.

In Mexico it is quite common for the teosinte to hybridize with the Mexican corn, through the agency of the wind, and the product is well-known under the name of "dog corn."

In my own extensive experiments with teosinte, no difficulty was experienced in effecting hybridi-

Primitive Types of Corn

Mr. Burbank has experimented very extensively with primitive types of corn, the seed for which was sent him from Mexico. The three specimens at the left are contrasted with the head of rye at the right; yet the similarity is sufficient to suggest the actual botanical relationship that exists. Corn is a true cereal, but it has departed rather widely from the traditions of its race.

zation, after I had succeeded in making the plant flower at the right season.

Left to itself, the plant in this part of California does not bloom until after even the latest varieties of corn are through blooming. It will produce seed only in the southern part of Florida, except the new varieties lately sent me from the high mountains of Mexico, where it necessarily had to adapt itself to a shorter season. I was able, however, by starting the teosinte in the greenhouse, and thus securing fine, large plants to set out in May, and by placing these in the hottest possible positions and fertilizing them heavily, to cause the plant to bloom much earlier.

This was further facilitated by removing all side shoots, so that the energies of the plant could be centered on the production of pollen.

My hybridizing experiments demonstrated clearly enough the affinity of the teosinte with the cultivated corn plant. They also convinced me that this is without question the parent of the cultivated plant.

Tracing Ancestral Forms and Habits

The experiments that seemed demonstrative as to this were made partly with the aid of a primitive form of corn known as the single-husked corn, *Zea tunicata*, of which I received specimens from Mexico. This I believe to be the true primitive

type of corn—that is to say, the first corn after advancing from the original type of the teosinte.

The seed of the half ear of fine yellow corn of this primitive type that was received from Mexico was planted. The plants that grew from this seed showed the widest variation. Every one knows that the cultivated corn bears its pollenate flowers or tassels at the top of the stem, and its pistillate flowers marked by tufts of so-called corn silk—and subsequently, of course, producing the ears—in the axils of the leaves far down on the stalk.

Teosinte bears small tassels at the top of each stalk, in competition with the diminutive ones all along down the stalk. But some of the plants of my single-husked corn bore both tassel and silk together at the top of the stalk. Others bore silk and tassel mingled up and down the stalk, like teosinte.

The ears of corn that developed sometimes showed clusters of kernels of the size, shape, color, and general appearance of the Kaffir corn. Others bore long tassels with numerous kernels.

By selecting among these different types, I have been able to develop races of corn that, I am confident, represent the primitive type, running back to the form of teosinte, and thus clearly enough demonstrating the origin of the plant that occupies so important a place among the present day farm

Corn Hybrids

At the right, an ear of sweet corn; at the left, ears of Teosinte; in the middle, hybrids between the two. Teosinte is believed to be the original stock from which the developed corn sprang. The ear of Teosinte, however, suggests the head of wheat rather than the seed-group of its developed descendant.

crops, even if the abundant evidence had not already been developed by my own experiments.

In the course of a few generations of selective breeding, I had a race of descendants of the single-husked or tunicate corn, three-quarters of the individuals of which produced kernels only at the top of the stalk. By farther selections a race could readily be produced that would bear its kernels exclusively in this location.

As a rule the plants that thus produce kernels at the top of the stalk produce no ears in the ordinary location, although a few generations earlier they had produced the grain about equally in the two locations.

The chief interest of the experiment lies in the demonstration that our cultivated corn, which now shows the anomalous habit of bearing its pollenate flowers only at the top of the stalk and its fruit on the main stem below, was originally a grass with the characteristic habit of bearing its grain at the top of the stalk, just as other grasses—including wheat and rye and barley, oats, rice, sugar-cane, and Kaffir corn—habitually do to this day.

The presumption is that as the corn was developed under cultivation, and evolved a large ear which attained inordinate size and weight, it became expedient to grow this ear on the part of the stalk that was strong enough to support it.

Obviously an ear of corn of the modern variety could not be supported on the slender tip of the stalk where the tassels grow.

We saw in the case of the potato plant that was grafted on the stem of the tomato, that the tuber-bearing buds might put out from the axils of the leaves under these exceptional circumstances.

Just what the circumstances may have been that led to the bearing of its fruit buds exclusively in the leaf axils in the case of the corn, we of course cannot know. But presumably the anomaly first appeared as a "sport", due without doubt to some altered conditions of nutrition, from being placed under unusual environment, and some one had the intelligence to select this sport and breed from it, with the result of developing a race of corn bearing grain on the stalk that gradually supplanted the old form altogether—except, indeed, that the wild teosinte maintained the traditions of its ancestors, unspoiled by cultivation.

I may add that the experiment of running the tunicate corn back to the primeval wild type by selective breeding is a much more simple one than would be the attempt to run it forward within a few generations to the plane of the good varieties of cultivated corn, but even this is comparatively easy of accomplishment.

To stimulate and accelerate degenerative

A Teosinte-Corn Hybrid, in the Stalk

The home of Teosinte is Mexico, and the plant there takes on a more or less tropical growth. It retains its tendency to giganticism when reared in northern climates; and such hybrids as this frequently attain a height of nineteen feet. The qualities of the wild and the civilized parent are curiously blended in the offspring.

processes is comparatively easy; to make progress, as civilized man interprets progress, is far more difficult.

One reason at least for this is that the qualities that man prizes in a cultivated vegetable are usually not those that adapt the plant to make its way in a state of nature. They are new innovations that to a certain extent run counter to the hereditary tendencies that have been fortified in the wild plant through countless generations of natural selection.

Rainbow Corn

Interesting experiments of another type that I have carried out in recent years have resulted in the development of a variety of corn that has the curious distinction of bearing leaves that are striped with various and sundry colors of the rainbow.

The parent form from which this new race was developed, I secured in 1908 from Germany. It was called the quadri-colored corn. Among the plants raised in the first season there were two stalks, and two only, that justified the name, their leaves being striped with yellow, white, crimson, and green.

The other plants of the lot bore green leaves like those of other corn plants, and the seeds of even the two best ones reverted.

I surmised that the corn was really a hybrid between the common green-leaved dwarf corn and the old Japanese variegated corn, sometimes spoken of botanically as *Zea mais variegata.* The fact that it was a hybrid stock gave the plant additional interest, however, and I determined to experiment farther with it.

The ears of corn themselves gave further evidence of their crossbred origin. Some of them were red both as to cob and kernel, and others bore yellow kernels and white cobs. The stalks varied in height from two and a half to six feet.

The best plant of the lot was selected, and from the three ears it bore I raised about six hundred plants.

About one-third of these hybrids of the second generation resembled their parent plant in having leaves striped in four colors. The rest reverted to the form of their Japanese grand-parent; a plant with variegated leaves that first came from Japan, and which has been known in this country for the past thirty years.

From the best of the quadricolor stalks I took suckers, and developed in this way a good-sized patch of corn from cuttings, perhaps the first cornfield ever raised by this method. All of these suckers being from an original quadricolor plant, of course reproduced the qualities of the parent

"Pod" Corn Variations

Here are a few of the anomalous types of corn growing in a sort of pod, that probably represent stages of evolution of corn during the process of its development. These specimens were of course raised in Mr. Burbank's gardens in a recent year; but they are reminiscent of a time when the best ears of corn in existence were probably not very different from these.

form, just as we have seen to be the rule with all other plants reproduced by root division or cutting, or by grafting of cions.

The method of suckering these plants was to pull down the suckers from the old plants when the young were about one foot high. About two-thirds of the foliage was cut back, leaving the stalk with shortened leaves about two to three inches in length. These were placed in pure sand in a moist place away from the wind for a day or two, but in the bright sun, and after a week when they showed signs of making growth they were transplanted into rows in the field.

Unfortunately, the suckering was not done early enough in the season to give all the new plants time to ripen a crop of corn. If they had been planted even three or four days earlier, all would have been well. As it was, only about half or two-thirds of the plants ripened their crop.

Of course the plants had been hand-pollenized to avoid danger of vitiating the strain with wind-borne pollen from ordinary corn tassels.

To guard absolutely against the danger of cross-pollenizing, if there is any other corn in the neighborhood, it is necessary to cover the tassels with a paper bag while they are maturing and before they are pollenized. Pollenizing is effected by dusting a tassel with its load of pollen against

Ears of Corn-Teosinte Hybrid

These ears, as will be seen, have departed very radically from the snake-rattle type of the original Teosinte. On the other hand they quite as obviously lack a good deal of conforming to the accepted standards of the developed corn. They have peculiar interest as representing another stage of the evolution through which the plant doubtless passed in the course of its development, under guidance of the aborigines of southwestern America.

the corn silks; these filamentous threads being of course the pistils of the corn flower. Each thread leads to an ovule that becomes a grain of corn in due course, after the nucleus of the pollen grain has made its way down the entire thread to unite with it.

I may add that the corn raised from the suckers proved fully as good in all respects as that raised from originally planted seed, when removed early enough in the season and properly treated, the weight of grain per acre being fully as great. But the stalks were much shorter and more compact than those of the other plants.

The object of suckering, of course, was to secure a large crop of quadricolor corn in order that the experiments might be carried out more extensively in the next generation.

The attempt was altogether successful. Not only did we secure an abundant supply of the quadricolor, but I found also two stalks among many that bore leaves in which the tendency of striping with varied colors had been greatly accentuated, producing a variety that might be called multicolor corn.

In addition to the four colors borne by the other plants, these had stripes of bronze and chocolate, and arranged in far more pleasing manner than in any of the former plants.

More Like Wheat Than Corn

This is another corn-teosinte hybrid, illustrating yet another stage of development. These heads of grain bear greater resemblance to heads of wheat than to ears of corn; yet their future possibilities are adumbrated in the swollen kernels and the tendency to discard the swaddling-cloth bracts.

It was by selecting seed from these plants that I grew in the next generation a number of stalks in which this tendency to multiple striping was accentuated, thus producing a race of corn with leaves beautifully striped in six colors, to which the name Rainbow Corn has been given.

In perfecting the variety, nothing further was necessary than to select seed from the plants that showed the most even distribution of the stripes, and the most vivid display of color, as well as uniformity of size and early ripening, as this was a very late maturing variety, even for California. In earlier generations there had been a marked tendency to variation, some plants producing only a single stripe of red, some only a stripe or two of yellow or white. But by rigid selection through several years these variants were eliminated, and a variety produced that may be depended on to exhibit rainbow leaves of a pretty uniform type.

My further experiments with this variety consisted of crossing the Rainbow Corn with some of the sweet corns, in the hope of giving to this handsome ornamental plant the capacity to bear sweet corn of good quality.

These experiments are still under way, but they give no great promise of immediate success, as the stripe seems to be recessive.

A rainbow-leaved corn that bears good edible

ears would constitute a notable addition to the very small company of habitants of the vegetable garden that are prized equally for their ornamental qualities and their food product.

Extra-Early Sweet Corn

My earlier experiments with corn date back to the Massachusetts period when I was developing the Burbank potato.

I recall a small success that at the time seemed to me quite notable, gained through a trick in the cultivation of sweet corn, that is not without interest.

I had learned the value of a very early sweet corn, and I devised a method of forcing the growth so that I was able to put my corn on the market in advance of anyone else in the neighborhood, and therefore to sell it at a fancy price. Many a time I was able to take a buggy load of corn from Lunenberg, where my place was located, to Fitchburg, and return with $50 or $60 as the selling price of what I could load on a common one horse spring wagon.

I had a complete monopoly of the early sweet corn market in the manufacturing city for three or four years, and my early corn brought usually 50 cents per dozen ears, although a week or two later any amount of corn could be bought for a fraction of that sum.

Various Stages of Development

Here are corn-teosinte hybrids ranging all the way from the condition of the primitive parent to that of the cultivated descendant. The ears at the bottom show close resemblance to the original teosinte. Going from right to left in the picture, we see evidences of improvement all along the line, until finally a really presentable ear of corn appears at the left. The picture furnishes a striking illustration of the segregation of characters often to be observed in the various members of the same fraternity of a hybrid race.

One of the secrets was in germinating the coı
I obtained fresh stable manure in the proper s(
son, and mixed this with leaf-mould, about h
and half. Corn placed in this when it was mo
and warm would germinate rapidly.

When the young roots were from two to six
eight inches in length, and the tops had made
growth of half an inch or so, I would plant the
sprouted grains in ordinary drills, dropping the
in just as corn would be dropped, no attenti
whatever being paid to the way they fall—wheth
with roots down or up.

A half inch covering of dirt being put over t
sprouted grain, it was nothing unusual to fi
shoots coming through the soil the next mornin,

And this early start would enable the plants
grow marketable ears at least a week earlier th
they would have done had the seed been planted
the ordinary way. The growth of the plants coı
be further stimulated by placing a small quant
of bone meal, or of a good nitrogenous fertili
containing a certain amount of phosphorus, in t
soil about the roots.

Preliminary to this method, I had made (
tremely useful selections of the earliest-ripeni
ears for a number of seasons.

Early Hybridizing Experiments

My experiments of this early period were ı

confined to methods of germinating and forced cultivation, but included also hybridizing tests.

My principal work was in crossing the black Mexican corn, the common sweet corn, and the New England yellow field corn. There was, of course, no difficulty in effecting crossing, but I found it very difficult to fix any good variety. These were the first experiments in this special line ever made with corn. They have of course been duplicated a thousand times since.

The most important experiments that I made had to do with crossing the yellow field corn with the Early Minnesota and other varieties of sweet corn, my intention being to produce a sweet corn with yellow kernels. There was a demand for such a variety, and none existed at that time.

I succeeded in producing hybrids that combined the yellow color of the field corn with the sweetness of the other variety, but had not thoroughly fixed the new variety so that it would uniformly breed true from seed at the time when I removed to California, in 1875; and this interrupted the corn experiments.

In the meantime, however, I had gained valuable lessons in heredity from observation of the cross-bred corn.

In the second generation numerous fine pure yellow ears were obtained without a trace of white,

A Freak Ear of Corn

This curious seed cluster was developed in the course of the hybridizing experiments with teosinte and corn. Doubtless it tells the story—did we only know how to read it—of some ancestral strain in which the seeds grow in a rounded cluster, little suggestive of the long ear that characterizes the modern product. But the kernels of this freak ear have after all a good deal of the corn quality.

but a part of the kernels were hard and smooth, and not the wrinkled sweet corn that was desired. In the following generation, when the corn was grown in California, I obtained some first-class ears with almost their entire lot of kernels wrinkled, and was confident that in another year I could have obtained the variety desired; namely, one that would bear exclusively wrinkled or sweet corn kernels of a yellow color.

But the pressure of other work led me to abandon the experiments at this stage.

There is peculiar interest, in the light of more recent knowledge, in noting the results of these early crossbreeding experiments, as just related. It will be observed that I had no difficulty in obtaining crossbred corn with the yellow kernels of one of the parent forms, but that it was difficult to secure a complete ear of wrinkled sweet corn kernels.

Starch Versus Sugar

To understand the conditions clearly, it should be explained that the kernel of the sweet corn differs from that of field corn in that it contains a large percentage of sugar in solution, and that the wrinkling of the kernel is the outward sign of this condition.

The smooth kernel, on the other hand, is one in which the sugar content has been largely trans-

Another Evidence of Old Heredity

Here we see a corn plant bearing a complete, although very primitive, ear in the midst of its pollen-tassel. All the other familiar cereals except the corn bear their seed bracts in this way. Corn has developed the habit of bearing only the pollen tassel at the top, placing the seed-head lower down on the stalk, where the stalk has strength to support it. This specimen shows an interesting reversion to the primitive type.

formed into starch, and deposited in this insoluble condition.

More recent experiments have shown that whiteness versus yellowness of kernel constitutes a pair of hereditary characters, in which yellowness is dominant. Similarly starchiness versus sweetness of kernel constitutes another pair of characters, in which starchiness is dominant. This being understood, we can predict with some certainty what will occur when such a cross is made as that of my early experiments in hybridizing the field corn and the sweet corn.

The crossbreds of the first generation will have ears with yellow kernels, that are all starchy like the field corn kernels, because yellowness and starchiness are dominant qualities. But the offspring of the second generation will show a certain proportion in which the recessive characters of whiteness and of sweetness reappear.

Thus in the second generation we shall have yellow kernels that are starchy, and others that are sweet, and white kernels also of both kinds.

And the interest of the experiment is enhanced by the fact that the kernels showing these different characteristics are likely to be distributed on the same ear. In many plant breeding experiments we have no tangible feature to guide us as to the quality of the fruit. Some of the seeds of

What to Work for in Corn

The ear at the left shows corn well filled out at the butt. The picture at the right shows the same ear well filled at the tip. The presence of well filled kernels at both extremities, proves that this corn is of good hereditary strain, and also that it has been fully pollenized. Ears of corn used for seed should always be carefully examined with reference to this quality of bearing well filled kernels at either end. The kernels in the middle should be well filled, as a matter of course.

a hybrid blackberry, for example, may bear factors for thornlessness, while others bear factors for thorns. But this can be shown only when the seeds have been planted and have germinated.

In the case of the corn, on the other hand, the qualities of the individual kernels are revealed in the outward appearance of the kernels themselves. The kernel that bears the factors for yellowness will be yellow; the kernel that bears the factor for starchiness will be plump and rounded; and the kernel that bears the factor for sweetness will be wrinkled because of its sugary content.

So a glance at the crossbred ear of corn reveals at once the story of its ancestry.

So striking is the illustration of Mendelian heredity when yellow field corn and white sweet corn are crossed, as in my early experiments, that recent tests, in which actual count of the different types of kernels has been made, have shown results of mathematical exactness.

Thus in an experiment recorded by Mr. R. H. Lock, of Cambridge University, in which a smooth yellow type of corn was crossed with a wrinkled white variety, the grains of different colors obtained from a certain number of ears borne by the plants of the second generation were distributed almost as evenly as if the work had been done by hand by a careful human calculator.

The Power of Environment

These are typical ears of corn received from a number of middle western experiment stations. They show the wide range of variation due simply to environment and selection. There is the closest similarity as to general form, the arrangement of kernels, etc. But the marked variation in size is noteworthy. Consider the difference in weight between a thousand ears of the largest and a thousand of the smallest here shown. The difference would be notable indeed as measured in dollars and cents—and the moral for the practical corn-grower is obvious.

The precise result was this: (1) Smooth yellow grains 2,869, or 25.3 per cent.; (2) smooth white grains 2,933, or 25.7 per cent.; (3) wrinkled yellow grains 2,798, or 24.5 per cent; (4) wrinkled white grains 2,803, or 24.5 per cent.

We have seen that the condition of whiteness and the wrinkled condition (due to large sugar content) are recessive traits. Therefore if we plant the wrinkled white kernels we may expect sugar corn, the ears of which will be uniformly of that type.

But what we wished to secure, it will be recalled, was an ear bearing only yellow wrinkled kernels. There are as many of these as of the others on the ears of the second-generation hybrids. But they will not all breed true, because yellowness is a dominant factor, and so in a certain number of the yellow kernels the quality of whiteness exists as a recessive trait in hiding, that will reappear in the next generation.

All the progeny of yellow wrinkled kernels will be *wrinkled* because the wrinkled condition is recessive; but only about one in four of these kernels will produce *yellow* progeny with certainty.

And no one can tell from mere inspection which of the four is the pure dominant and which the mixed dominant that will have a certain proportion of white offspring.

Mr. Burbank's Extra Early Sweet Corn

This is a bantam corn and bears earlier than any other corn Mr. Burbank has produced. It represents the present outcome of experiments that were started when he was a boy in Massachusetts. As the name indicates, the corn bears extra early; it is also extra sweet.

This, of course, accords perfectly with the results of my experiments, as just recorded. But the new tests, which explain the distribution of kernels of different colors, and enables us to predict the manner of their distribution, give added interest to the earlier observations.

I should add, however, that whereas it is usual for the crossbred kernels to show this mixed distribution on a single ear, in more recent experiments, in which the Orange sweet corn and a late white variety were crossed, I have secured a product in which there was a pure white ear that exhibited all the qualities of the orange except color, and in another case a pure yellow ear was produced which showed the characteristics of the late white, including the large number of rows of kernels.

This is altogether unusual in crossing yellow and white varieties of corn, and the anomaly is not easy to explain.

Breeding for Varied Qualities

My other experiments with corn have been rather numerous, but have largely been concerned with minor details, such as the development through selection of a corn that will produce ears bearing a large number of rows of kernels.

I have been able in three years, working with Stowell's Evergreen Corn, to produce a few ears

with eighteen to twenty-two rows to the ear, making it clear that by extending the experiments it would be possible to fix a variety growing uniformly twenty-two rows of kernels.

Other experiments have shown the feasibility of changing the form of the kernels, making them long, broad, and of uniform size. Attention has also been paid to the production of corn that would fill out all the kernels uniformly, instead of producing a certain number of nubbins as corn is prone to do.

The size of the stalk and the number of ears to the stalk are also matters that are subject to easy modification through selection. I have referred in another connection to experiments of others, in which the location of the ear on the stalk was lowered or raised at will in a few generations, and made to droop or stand erect as desired, through selection.

I myself have developed a race of corn with gigantic stalks, in which the ears are borne so high that a man of average height can barely reach them from the ground. This was done for experimental purposes, and not because a variety of this kind would have commercial value. I have personally produced and introduced four distinct new varieties of corn, including the two unique ornamental varieties, and two improved extra early

Mr. Burbank's Giant Field Corn

Here is a Burbank corn-field, growing a variety selected for gigantic size. The average height of the stalks in this field was well above twelve feet. Under ordinary circumstances, there is no great advantage in having the corn grow so high; but the experiment is interesting as showing the possibilities of development. After all, in taking on this towering growth, the corn is only harking back to its teosinte ancestor.

sweet corns, besides several strains that have been greatly improved by selection and then turned over to various seedsmen.

Reference has been made also to the experiments through which the kernels of corn were made to produce more protein or more starch, as the case might be. These experiments have practical importance because a corn to be used as fodder should have a high protein content, whereas grain to be used for making starch or for purposes of distillation should have a high starch content. The oil content can also be similarly increased or diminished at will.

By selection alone it is possible to modify these qualities, and they can be accentuated, modified, combined or separated through the crossing of different varieties.

All in all, the great American cereal offers interest for the plant developer somewhat commensurate with the economic importance of the plant itself. Much has been done, but there is still ample opportunity for the improvement of different varieties, and for the development of specialized new varieties differing as to their sugar content, as to time of ripening, and the like.

No plant is easier to experiment with for the amateur, and few plants offer better prospects of interesting developments.

Wheat Germinating on Ice

This picture shows an experiment that illustrates the hardiness and virility of the wheat. It is obviously a plant that can germinate in an almost Arctic temperature. Yet the original home of wheat, so far as we know, was southwestern Asia. Such an experiment as this, however, suggests that the wheat has ancestors that grew far to the north.

Getting the Most Out of the Small Grains

Improvements In Wheat, Oats, Barley

NO one needs to be told of the part that the small grains take in the scheme of the world's agricultural activities.

Their place to-day is what it has been from the earliest historic periods. Indeed the ethnologists who probe into the prehistoric period tell us that the lake dwellers were cultivators of wheat, and it is known that this plant was under cultivation in Egypt and Mesopotamia at the very earliest period of which there is any record.

Then as now the little company of grasses represented by wheat, barley, rye, and oats occupied a pre-eminent position in supplying man and his domesticated animals with suitable foods.

In recent years, to be sure, the American product, Indian corn, has gained supremacy over the small grains as food for domesticated animals, and has attained a notable place as a supplier of

food for man himself. But important as this new cereal is, it by no means takes the place of the others. Wheat and rye in particular stand unchallenged as the producers of the chief vegetable foods of mankind throughout the civilized world. Oats constitute the most highly prized food for man's chief helper, the horse; and barley is raised in enormous quantities for purposes of fermentation to produce beverages that retain their popularity generation after generation, whatever may be said as to their wholesomeness.

The relatively close relationship of these four grasses is obvious to the most casual observer. Wheat, rye, and barley in particular are so similar that only the practiced eye can distinguish between them with certainty when growing in the field. They are closely related in the eye of the botanist as well, and what may be said of one of them with regard to possibilities of development applies, with minor modifications, to them all.

They are plants that, having been for ages under cultivation, have developed many varieties.

But, on the other hand, the varieties that asume commercial importance are relatively fixed, owing to the fact that they have always been grown in mass, thus giving no great opportunity for variation, and no necessity for cross-fertilization. These are the good and sufficient reasons why they get

few varieties in the field grains and so many in corn and singly cultivated garden vegetables, in which variation is quite evident and varieties are easily segregated.

It is obviously necessary that a plant grown from the seed, and for its seed, must reproduce itself accurately from generation to generation; otherwise the agriculturist could have no assurance as to what might come forth when he sows his grain.

In point of fact, the numerous varieties have become fixed so that each may be sown with a large measure of assurance that the crop will have the uniform character of the seed. The differences among the different varieties have to do with size of grain, productivity, season of ripening, protein content, quality of so-called hardness, which is important in bread-making, color of grain, peculiarities as to beards, chaff, and the like; and—perhaps most notable of all—condition of susceptibility or immunity to the attacks of the fungus known as rust, which is the chief enemy of the wheat, and a perpetual menace to the crop.

A Microscopic Pest

There are always penalties associated with any specialized development in a cultivated plant or a domesticated animal.

In the case of the small grains, the penalty of

specialized breeding in which selection has been made generation after generation with reference to the quality of the seed has been the gradual loss on the part of many varieties of the cereals of the power to ward off the attacks of a fungus pest that finds their stalks its favorite feeding ground.

This pest is known to the farmer as "rust," because in many forms it gives to the stalks of the plant, once it is fairly lodged and under development, a blotched, reddish brown appearance suggestive of the scales of rust that appear on a metallic surface.

To the botanist the fungus is known as a member of the tribe of so-called *Euridineial* or Cup Fungi. The most familiar species is known as *Puccinia graminis.*

The precise history of this parasite has been very difficult to trace. It is known, however, that the germinal matter lodges on the stalks of the grain in the form of minute spores, and that these send little rootlets into the substance of the grain cell and sap its vitality.

It is further known that at one stage of their career some varieties of rust plant lodge on the leaves of the common barberry and there develop another type of spores. This fact has made the botanist look askance at the barberry, not unnaturally. Yet it is known that rust attacks the wheat

Mr. Burbank Among His 1914 Wheat Experiments

Mr. Burbank is now experimenting extensively with hybrid wheats at Santa Rosa. He has wild wheat from Palestine, and cultivated wheats from all over the world; and he is blending the strains and watching results. The luxuriant growth of some of his pupils is illustrated in this picture.

in Australia where the barberry does not grow; and experiments have also shown that the rust may be propagated for an indefinite period without passing through the phase of development in which the barberry is its best.

So the elimination of the barberry does not constitute the important agency in fighting the rust that the botanist once hoped it might.

Nor has any other agency been suggested that will combat the pest. Once its spores have found lodgment, it is obvious that there could be no means of spraying or otherwise giving treatment for their destruction or removal that could be applied to a host plant that is grown not individually or in small clumps, like orchard fruits or garden vegetables, but in fields that aggregate millions of acres.

So it has long been recognized that the battle with the rust plant must be fought out along different lines. There could be no hope of eradicating the pest except by making the grain plant itself resistant to the attacks of the enemy.

Destruction Wrought by the Rust

Experiments in selective breeding, through which new races of wheat have been developed by saving for seeding purposes the grain of plants that proved individually resistant to the rust, have long been carried out more or less systematically.

Partly in this way, and partly perhaps through accidental development in regions where the rust does not prevail, some varieties of wheat have been introduced that show a large measure of immunity to the disease. But unfortunately these for the most part have been plants that did not produce grain of very good quality. In general the favorite wheats of the world have remained subject to the attacks of the fungus. Their degree of immunity in any given season has depended upon accidental conditions of weather that interfered with the development or spread of spores of the rust fungus rather than upon any inherent resistance of the cereal itself.

Thus it is familiar experience everywhere that the farmer cannot have any full assurance as to the amount of his grain crop until the grain approaches the ripening stage; because at any time the invisible spores of the rust may sweep as a devastating horde across his fields and, finding lodgement on the grain stalks, so devitalize them as greatly to reduce their capacity for seed formation.

The attempt has been made many times to estimate the average loss that results to the grain growers of the world—and hence, of course, ultimately to the consumers in every rank of life—from the attacks of this microscopic but all-pow-

Some Results of 1914 Wheat Experiments

This is a sample cluster of varying heads of wheat collected in Mr. Burbank's experiment garden in the summer of 1914. A glance at the picture shows the extraordinary range of variation among these crossbred wheats; and suggests the possibilities of development of any number of new varieties.

erful enemy. It is conservatively estimated, for example, that the loss to the wheat growers of Australia is from ten to fifteen million dollars a year. Yet Australia is relatively free from the pest. In an old wheat country like Prussia, where the rust has gained a more secure foothold, the losses are enormously greater.

It has been estimated that in a single season the loss from rust on the various small grains in Prussia alone was not less than $100,000,000.

In America the losses from rust vary greatly from year to year; but there is no season when the destruction wrought by this pest would not be calculable in millions of dollars. There are exceptional seasons when in entire regions the wheat crop is almost totally destroyed and other seasons in which the losses amount to a high percentage of the total crop.

All in all, the microscopic uredospore must be listed among the most important and most menacing enemies of our race.

A pest that perpetually threatens our chief food product must surely be so considered, notwithstanding the individual insignificance of its members.

The Plant-Developer to the Rescue

It is obvious, then, that there is no single task that the plant developer could undertake that

would give larger promise of benefit to mankind than the task of rendering the cereals immune to the attacks of the rust fungus.

But it is also obvious that the task is one that should be carried out under the auspices of the government, rather than as an individual effort. Nevertheless a very notable beginning has been made in the direction of developing immune races of wheat through the efforts of an individual experimenter, who, however, had the backing of a university position and was therefore not under necessity to have his experiments attain commercial success.

The experimenter in question is Professor R. H. Biffen of the Agricultural Department of Cambridge University, England. His experiments with wheat constitute by far the most satisfactory investigations in plant development that have been carried out under the guidance of the new Mendelian principles of heredity.

The investigation through which Professor Biffen was enabled to develop an immune race of wheat in a few generations promises to be of immense economic importance. The story of this development is too important not to be told in some detail.

In order to understand Professor Biffen's success in developing an immune race of wheat, it is

Selected Wheat Heads

This bunch of bearded wheat heads was selected by Mr. Burbank as representative of a certain type of crossbred wheat with which further experiments are to be made. It is but one of a large number of selected clusters of quite different types, as the preceding picture will make readily comprehensible.

necessary to review briefly the preliminary studies through which he familiarized himself with the hereditary characteristics of the wheat plant.

Professor Biffen had given attention to the development of the wheat through the ordinary methods of selection as early as 1900, and before anything had been heard of the researches of Mendel, which, as we have elsewhere pointed out, were quite unknown to anyone after the death of Mendel himself in 1884 until about the beginning of our new century. But he had not proceeded far before three observers, De Vries, Correns, and Tschermak, independently discovered and made known the forgotten work of Mendel, and, as Professor Biffen himself says, "changed the whole aspect of his problem."

It was at once obvious to Professor Biffen that wheat offers opportunity for hybridizing experiments closely comparable to those that Mendel had performed with the pea.

Both of these plants are normally self-fertilized, their stamens and pistils being enclosed in receptacles that are never opened and made accessible to insects or subject to wind pollenation.

This makes the hand pollenization of the plants a rather tedious and delicate task.

But once this is effected, the further experiments are greatly facilitated by the fact that there

is no danger of unintended cross-pollenizing—in other words, the plants of the second and subsequent generations will normally inbreed and thus reveal hereditary potentialities without further attention from the experimenter; whereas with most other plants of another habit it is necessary to guard constantly against cross-fertilization.

Mendelian Clues

The essential facts of Mendelian discovery with regard to "unit" characters and their grouping into pairs, in which one character is dominant and one recessive, have been more than once called to our attention and have been illustrated again and again with instances drawn from my own plant experiments.

The cases of the black and white blackberries, the thorny and thornless blackberry, and of stone-bearing and stoneless plums, among others, will be recalled.

But we have also observed cases in which the characters of two parents seemed to be blended in the offspring, there being no clear dominance of one character over another. Such was the case, for example, with the Sunberry, the Primus berry, and the Plumcot.

Now it is peculiarly interesting to note, in the light of our experiments with various fruits and flowers of widely different orders, that Professor

Seven Headed Wheat

Sometimes wheat shows a tendency to develop several heads on a single main stalk. At one time, Mr. Burbank thought of developing cereals of this type, improving the stalk to make it able to bear the increased weight, in the hope of thus increasing the yield. But he has decided that on the whole it is better to increase the quality of the individual head rather than to increase the number of heads.

Biffen was able to analyze the diverse qualities of the various wheats with which he experimented and to discover that different groups of unit characters operated differently in heredity. Some of the pairs showed dominance and recessiveness; others showed an irregular or partial dominance; while other pairs showed the blending of characters, so that the offspring was intermediate between the parents, there being no apparent tendency to dominance or recessiveness.

Yet all of these characters, whether manifesting the phenomena of dominance in the hybrid of the first generation or not, showed the same tendency to segregation in the succeeding generation, and to segregation along the familiar Mendelian lines; that is to say, one offspring in four would reveal the first character only, the second and third offspring were mixed as to the pair of characters, and the fourth would show only the second character.

It was necessary only to plant the individual grains of wheat in plots by themselves, and to note the qualities of the grains of each (that is to say, the qualities of the offspring of the first filial generation) to make sure as to the position of each individual in the Mendelian scale (whether pure or mixed in its heredity as to its given factor), and thus to be able to select pure types that would

breed true; and, what is perhaps equally important, to eliminate the impure types that would not breed true.

Dominant and Recessive Characters

It will be of interest to note a few characters that Professor Biffen particularly studied and the groups into which they fall.

As to characters that show the phenomena of pure dominance and recessiveness, the following among others were clearly revealed: Beardless ears of grain are dominant to the bearded ears; keeled glumes to round glumes; lax ears to compact ears; red chaff to white chaff; red grain to white grain; thick and hollow stem to thin and solid stem; rough leaf surface to smooth leaf surface; bristles on the stem to a smooth stem; hard, translucent endosperm (central grain substance) to soft opaque endosperm; and, finally, susceptibility to the attacks of yellow rust was dominant to immunity to yellow rust.

This implies, as the reader is aware, that in each case of those just listed, when two plants represented by the opposite characters are crossed, the offspring will show the first-named character to the exclusion of the other in the first generation, but the excluded character will reappear in one fourth of the offspring of the second generation.

Breeding a wheat with beardless ears and white grain, for example, with a wheat having bearded ears and red grain, all the progeny will be beardless and red-grained; but bearded ears and white grain will reappear, in various combinations, in one fourth of the progeny of the second generation.

It is never safe for the plant developer to draw exact inferences as to the hereditary tendencies of one plant from observation of a quite different plant. Nevertheless it is of interest to observe certain analogies between the wheat grains as studied by Professor Biffen and certain of our plant developments already cited.

In particular we may note that red grain is dominant to white grain, suggesting what we have said as to the dominance of black blackberries over white blackberries.

Again, the rough leaf surface and bristly stem of the wheat proved dominant to the smooth leaf and smooth stem, suggesting the case of our thorny stemmed briars in which the thorns proved dominant to smoothness of stem.

But doubtless the most important revelation made by Professor Biffen's investigation was the fact that susceptibility to rust was dominant to immunity to rust.

This means that when a susceptible type of wheat is crossed with an immune one, all the off-

spring will be susceptible. But it means also that the recessive quality of immunity will reappear in one fourth of the offspring of the second generation.

And thereby hangs the tale of Professor Biffen's great achievement, as will appear in a moment.

Characters That Do Not "Mendelize"

Before following this let us glance at the other groups of unit characters which Professor Biffen found not subject clearly to the rules of dominance and recessiveness.

These groups include fewer characters than those in the dominant list, partly perhaps because it is obviously more difficult to study characters that do not show the clear phenomena of dominance and recessiveness. But these groups are highly interesting none the less. The unit characters that showed what Professor Biffen speaks of as irregular dominance as studied in this investigation, were only two, namely: (1) felted glumes versus glabrous glumes; and (2) gray colored glumes versus red or white glumes.

The glume, perhaps it should be explained, is a bract that has no particular interest for anyone except the botanist, but which may serve admirably in checking the results of experimental breeding. The glumes have practical significance for the agriculturist, because their character deter-

A Sheaf of Oats

Mr. Burbank is experimenting with oats as well as with wheat. Hitherto he has not experimented very extensively with these or other cereals, except the corn, because he feels that this work lies rather beyond the resources of a private individual and should be carried out by the Government Experiment Stations and Agricultural Bureaus. Nevertheless he has found time to take a hand in the work, as this picture suggests.

mines to some extent the readiness with which the grain is shelled out in the thresher.

The interest in the different types of glumes as to smoothness and of color, in the present connection, centers about the fact that neither parent showed dominance in the first generation of the hybrid, the individual hybrids differing indefinitely.

In some cases there would be almost pure dominance; in others a blend of the characters. But in the second generation the characters were segregated just as if they had shown the typical phenomena of dominance and recessiveness in the first generation.

The third group of characters, in which there was uniform blending in the first generation of hybrids, with no tendency whatever to manifestation of dominance of one character over the other, found representation in the following pairs of unit characters: (1) lax ears versus tense ears; (2) large glumes versus small glumes; (3) long grains versus short grains; (4) early habit of ripening versus late habit of ripening.

As to each of these pairs of characters, the hybrids of the first generation were intermediate between the parents. For example, if a wheat having long grains was crossed with one having short grains, the hybrid bore wheat neither long

nor short but intermediate; and if a wheat that ripened early was crossed with one that ripened late, the hybrid offspring ripened their grain at an intermediate season, later than their early parent but earlier than their late one.

Yet here again—and this perhaps is most significant of all—there was segregation of characters in the second generation along the usual Mendelian lines. That is to say, the first generation hybrids that bore grain of medium length will produce offspring one fourth of which bear long grain and one fourth short grain, the other half bearing intermediate grain; and similarly the first generation hybrids that ripened their grain at an intermediate season, produce progeny one fourth of which ripened their grain early and one fourth late, the other half ripening their grain at the intermediate season.

The importance of this observation is that it shows that the Mendelian principle of the segregation and recombination of unit characters in second generation hybrids follows the same rule whether or not the characters show clear dominance in the first generation.

And if we look a little beneath the surface it will appear that there are hundreds or perhaps thousands of unit characters that for one reason or another do not show the phenomena of dom-

Wild Oats

The wild oat is provided with a curious "feeler," with which the seed burrows its way into the ground. The apparatus is not provided with the capacity for automatic motion, of course, but it twists about under the influence of moisture and varying conditions of heat, and ultimately effects the purpose of partially burying the seed.

inance in the first generation and hence are exceedingly difficult to trace, and yet which reappear segregated in new and varied combinations in the second generation, thus accounting for the extraordinary diversity of second generation hybrids to which our attention has been called again and again.

It is interesting to note that Professor Biffen found such conspicuous conditions as long grain and short grain to fail to manifest the phenomena of dominance and recessiveness.

Considering that tallness of vine had shown itself to be dominant over shortness of vine in Mendelian peas, it might perhaps have been expected, reasoning from analogy, that long grains of wheat would be dominant to short grains.

But I have already suggested that it is unwise to attempt to predict the hereditary tendencies of one plant from observation of another; and in particular it should be said that the stems of plants, as regards their fixity of hereditary tendency, are likely to be on a different plane from the flowers or fruit, or any other new characters.

The particular arrangement of floral envelope that characterizes the plant of to-day is of relatively recent development, and may be expected to be subject to greater fluctuations, or in other words to show greater plasticity under the disturbing

influences of hybridization. Professor Biffen even found that there was a difference in the manifestation of dominance and recessiveness with regard to certain characteristics between different varieties of wheat.

Thus in the matter of the glumes, where the parent that bore a felted glume was the variety known as "rough chaff," the felted glume proved dominant over the smooth glume. But where the felted parent was the variety known as rivet wheat, the phenomena of dominance were irregularly manifested, or manifested not at all. So hybrids of the rivet wheat were listed in the class of irregular dominants, as above outlined.

Practical Application of the New Knowledge

Having thus analyzed his wheat plants and made himself familiar with their hereditary possibilities, Professor Biffen was ready to make application of his knowledge to the improvement of existing varieties of wheat.

In particular he desired to produce a variety of wheat that would be immune to rust, yet would at the same time produce a good head of wheat having the quality described by the miller as "hardness"—a quality that is essential to the making of high grade flour, yet which some otherwise excellent wheats altogether lack.

Material was at hand for crossing experiments

in that there was a race of wheat known to be immune to the yellow rust which had not hitherto been thought of as solving the rust problem because it bore grain of very poor quality.

To Professor Biffen, armed with his new knowledge, it appeared that it should be possible to combine this immune wheat of poor quality with susceptible races of wheat bearing a good grain in such a way as to secure a new race that would present the good qualities of each parent and eliminate the bad qualities.

So he crossed a race of wheat that bore a grain susceptible to rust with the immune variety that bore the grain of poor quality, and developed a generation of crossbreds all of which were—quite as he had expected—susceptible to the attacks of the rust.

To the untrained plant experimenter it would have appeared that this experiment should be carried no further. Progress was apparently being made in the wrong direction; for whereas half the parents were immune to rust, all of the children were susceptible.

But Professor Biffen knew, as we have already seen, that susceptibility and immunity constituted a Mendelian pair of hereditary factors. So he knew that in the next generation one fourth of the hybrid plants would be immune to rust. And this

expectation was justified by results. The second generation hybrids showed diverse combinations of various other qualities that were under consideration, and a certain proportion of them revealed the combination of the desired quality of grain with the stems immune to the attacks of the rust fungus.

As immunity to rust is a recessive factor, it follows that the second generation hybrids that show such immunity will breed true to that character. Their offspring will be immune. But as regards certain other qualities, notably hardness, it was necessary to continue the experiment through a third generation, in order to discover which of the plants that were individually hard were pure dominants as regards the quality of hardness.

To ascertain this it was necessary only to plant the grains showing the desired quality in plots by themselves.

The individuals that produced only hard-grained offspring in the next generation were thus shown to be pure dominants for that quality. They constituted a fixed race and could be depended upon to breed absolutely true.

Thus the clear recognition of the qualities of Mendelian segregation, as applied to the different pairs of unit characters representing respectively

An Experiment With Rye

Since he is experimenting with the cereals, Mr. Burbank of course includes rye among the others. He made interesting experiments with this plant a good many years ago, and he is now extending them. The present experiments will include, probably, hybridization with other cereals.

desirable and undesirable qualities of the wheat, enabled Professor Biffen to produce in the third generation a fixed race of wheat having the desired qualities of grain and a plant stem that is immune to the yellow rust.

The seeds of this new variety being multiplied as rapidly as possible, a wheat was produced that promises to be of enormous importance to the grain growers of England.

It is obvious that a similar line of experiment should enable the plant developers of other countries to produce new varieties of wheat that will be immune to the various rusts, and thus to rid the agriculturist of one of the pests that of all others has hitherto rendered his calling precarious.

Possible Aid From the Wild Wheat

The greatest difficulty, doubtless, will be to secure varieties of wheat that are immune to the various rusts to utilize in crossbreeding.

Much further investigation will be needed before we can make sure as to the material that is available. But peculiar interest attaches to the investigations recently made by Mr. O. F. Cook, the biometrist in charge of crop acclimatization and adaptation of the U. S. Department of Agriculture, with reference to the wild wheats of Palestine, which were discovered by Mr. Aronson, a native of Palestine.

Mr. Cook's researches have shown that there are races of wheat growing wild in Southwestern Asia that are prototypes of the cultivated wheat. The resemblance of northern wild forms to the cultivated varieties is striking. Yet the differences are also conspicuous. The wild wheat has a looser, less compact head, and some varieties have the peculiarity of shedding the spikelets that hold the grain individually, each spikelet being provided with a barbed shaft which serves the purpose of helping the grain to attach itself or even to bury itself in the soil. All of which would be expected in a wild wheat, which is found also in the wild oats and rye as well as in rice.

The kernels of some wild wheats are not large, but some of them are of more or less edible quality.

A chief interest in the plant centers about its seeming immunity to rust. And the question at once arises as to whether it may not be possible to hybridize these wild wheats with the cultivated ones to secure resistance to disease as well as unusual variation, vigor, and hardiness.

Tests calculated to discover possibilities in this direction are now being made, and there is every reason to hope that they will have valuable results.

It may be added that the wild wheat is not universally self-fertilized. The stamens and pis-

A Sheaf of Barley

Barley, like the other cereals, offers good opportunities for the experimenter, notwithstanding the amount of work that has been done with it. The amateur should understand that experiments with the cereals may be made on a small scale, and that the results of such experiments may be of great economic importance. The remarkable results of Professor Biffin at Cambridge, England, in developing an immune variety of wheat, for example, were made on very small plots of land. Interesting results might doubtless be secured by hybridizing wheat and rye and barley.

tils of its flowers sometimes protrude and permit cross fertilization by the aid of the wind or insects. This may to some extent facilitate the hybridizing of the wild wheat with cultivated wheats.

But on the other hand, it will probably be desirable to eliminate this propensity from the new varieties after they are fixed for commercial use. For, as already pointed out, there are advantages in the self-fertilization of a grain like wheat, to prevent deterioration of the type by undesired crossing.

But the entire question of the hybridizing of the domesticated wheat with the wild type remains for future investigation. There is perhaps no single field of plant development that offers greater possibilities of usefulness. Fortunately several experimenters are alive to the importance of the subject, and it may be expected that their investigation will reveal its full possibilities in the near future.

As I have already pointed out, this work is pre-eminently one that should go forward under government auspices. My own experiments in this line with the wild wheat are necessarily limited, as I received specimens only last season.

A work that involves matters of such vast economic significance, having direct connection with the cost of living as applied to every member

of the community, should not be hampered by any financial restrictions, and should have the co-operation of investigators in many parts of the world; such co-operation as a government bureau alone can command.

During the past thirty years I have been experimenting in a desultory way with various grains and grasses, both of the best cultivated varieties and numerous wild species. But I have not as yet carried out serious experiments in crossing the cereals. I have selected and perfected, and some definite results are expected from work now in hand.

The interest already shown by the authorities of the Department of Agriculture gives sufficient assurance that the work will be carried forward energetically and efficiently. That it will lead to developments of vast importance, having direct bearing on the improvement of all the small grains, can scarcely be doubted.

—The little company of grasses, represented by Wheat, Barley, Rye and Oats, have, since prehistoric times, occupied a preeminent position in supplying man and his domesticated animals with suitable foods.

Manufacturing Food for Live Stock

Some Suggestions on Clover, Timothy, and Alfalfa

FORTY million acres devoted to it; an annual crop of seventy million tons, valued at something like three-quarters of a billion dollars.

Such is the record of hay in the United States.

And of course this takes no account of the other millions of acres that are devoted to pasturage, the crop of which would be hay if it were not harvested directly by browsing live stock. Just how much this would add to the value of the crop it is difficult to say. But without attempting an exact computation, it will be clear that the value of forage crops in America reaches a colossal figure.

There are many kinds of grass that may be found first and last in pasture and hay-field, but the one grass that over-shadows all others because of its universal popularity is that known as tim-

othy in most regions, and in some regions as herd's grass.

It may be of interest to recall that each name is merely borrowed from the name of the man who was instrumental in introducing this particular grass; one man being Timothy Hanson or Hanse, of Maryland, who is said to have brought the seed from England in 1720; the other being John Herd, who is alleged to have found the grass growing wild in a swamp in New Hampshire as early as 1700.

One of these men distributed the grass through Virginia and Carolina, the other through New England and New York.

From these regions it has spread in every direction, proving adaptable to all climates and soils, until it assumes pre-eminence in the pasture and hay-field quite unchallenged except by members of the clover family, with which it is commonly associated.

The clovers, to be sure, are not grasses in the technical sense of the word. Nor, indeed, have they the appearance of grasses even to the eye of the most casual observer. But they rival the grasses in their importance as fodder plants. In certain regards, as for instance in the amount of protein they bear, they outrival the grasses. Also in their capacity to produce successive crops in

Heads of Timothy

Doubtless the most popular of all the forage grasses in the eastern United States is the Timothy. In connection with clover, this may be said to be the typical meadow and pasture plant. Timothy is not so well adapted to the California climate and conditions, but Mr. Burbank has experimented with it nevertheless. This picture shows a bunch of his Timothy proteges.

the same season, some of the clovers, notably the more recently introduced alfalfa, are superior to the grasses proper.

But in general clover and timothy are mixed to form the hay-crop, the clover growing densely near the ground, and the timothy rising above it, and the two making a blend that is found exceedingly palatable by all herbivorous animals.

The fragrance of new mown hay suggests palatability to the human senses as well, and even though the hay-crop furnishes food for man only at second hand no one would be likely to question its wholesomeness.

Bettering the Clovers

There are certain of the clovers, nevertheless, that have a poisonous principle. Notable among these is a form of sweet clover not distantly related to the alfalfa, which grows in some of the States of the Middle West and produces an enormous crop which would have great value were it not that unfortunately the tissues of the plant contain a considerable percentage of a bitter alkaloid called brucine, which is highly poisonous, being closely related to the well-known drug strychnine.

A few years ago I received from Kansas samples of this plant, with the request that I develop from it a variety in which the brucine is

reduced to a minimum, or, if possible, wholly removed.

The seeds that I received were of various colors. My first move was to have the seeds sorted, placing white ones, black ones, and green and brown by themselves. The seeds were then planted in separate lots; a fifth lot being reserved for a mixture of the seeds of uncertain shades.

Thus it was possible at the outset to determine whether the production of plants having a large brucine content was associated with any particular color of seeds. Should such be found to be the case, the experiment would obviously be shortened, as only the plant bearing the minimum amount of brucine would be used for further testing. Experiments showed that the plants from the white seed apparently contained an appreciably less quantity of brucine than the black ones.

As an additional element in the selection, I chose, as is my custom, the seed plants that started very early in the Spring. From among these the next selection was made of the plants that had broad foliage and continued to make a very strong growth. Thus several objects were attained almost from the outset. A second selection along the same lines showed that some plants have a much smaller brucine content than others, and that it will be quite possible to separate these out

Soy Beans for Fodder

This picture illustrates a method of curing soy beans in shocks, like hay. The soy bean has high food value, owing to its large protein content, and it is coming to be a popular forage plant.

and thus produce a variety relatively free from poison.

Some similar experiments in improving peas, beans, and other plants related to the clovers, gave assurance that I should be successful in the present instance, merely by selective breeding, in producing a plant with relatively low brucine content, and the experiments even in their initial stages justify this belief.

Whether it may be necessary to resort to hybridizing experiments in order to eliminate the brucine altogether or to reduce it to a negligible minimum, remains to be seen.

The experiments were begun only in 1910.

It should be explained that the hybridizing of the plants of this group is relatively difficult, because the flowers are encased in a closed receptacle, as with the peas and beans, which belong to the same family with the clovers.

All of these so-called leguminous plants—and they are outnumbered only by the composite flowers—bear the stamens and pistils thus guarded, and are normally self-fertilized.

As already pointed out, this makes the experiment of hand-pollenizing these plants a rather tedious one. In the case of the clovers, the flowers being very small, it becomes a somewhat delicate operation as well. But the later stages of the

experiment are greatly facilitated by the fact that the flowers are self-fertilized. With these plants, as with the small grains, this becomes an important aid in fixing a type, and in maintaining a pure race once it has been developed.

For the most part, my experiments with the clovers have been made through selection, and without resort to hybridization. But in exceptional cases I have cross pollenated these plants, to test the possibilities of work in this line. I found that the process involves no great difficulties, notwithstanding the small size of the flowers.

In practice I found it better to remove all but two or three flowers in a clover head.

The remaining ones have the petals and stamens removed with a small pair of forceps, after which the application of pollen from another clover head presents no special difficulties; care being taken, of course, to see that the pistil is at the right stage of development.

Developing New Characteristics of Stem and Leaf

In the course of these experiments I have grown in the neighborhood of two hundred species of clover. Many of these are native species, some of which invaded my grounds unasked. Others have been received from far away regions, in particular from Peru, Bolivia, and Chile.

A Bed of Four-Leaved Clover

This interesting colony of four-leaved clover grows in Mr. Burbank's yard. It is an example among hundreds of experiments that Mr. Burbank has conducted for his own amusement, or for their scientific interest, with no thought of commercial results. All the clovers in this large bed bear four leaves, and they illustrate the possibility of fixing any given character by selection.

Whereas the white clover in its common native forms is a relatively small plant, dwarfed beside the red and crimson clovers, there are South American species or sub-species that are of relatively gigantic growth. One of these that I received from South America was a seeming "sport"—possibly due to an accidental hybridizing with some other species—that grew several times as fast as any of the others in a lot of seedlings.

A single plant of this giant variety would spread from four to six feet, the foliage being proportionately enlarged, while a neighboring plant would perhaps grow ten to fifteen inches.

Selection among these rapid growers enabled me to develop several varieties that had the characteristic of growing to quite uncloverlike size. But there is no sale for new clovers unless the seed can be furnished by the ton, and as I had no opportunity to produce seed on a large scale, the giant races were ignored, when they had ceased to interest me from an experimental standpoint.

I worked for a number of years also upon a clover that, without having exceptional qualities of stem, produced very large foliage. In this case also the development was made solely by selection, the largest leafed individuals of a fraternity being selected for preservation generation after generation.

In the same way I produced a five-leafed strain of clover from a sport that appeared among plants of the usual three-leafed type of white Dutch clover.

The four-leaved clover is of course well-known as an occasional sport. A five-leafed clover will appear in a lot of seedlings now and again, and there will be found a few five-leafed individuals among the plants grown from seed of this sport. It would, however, require many repetitions, seemingly, to fix a five-leafed race, the tendency to reversion to the familiar three-leafed type being very pronounced.

Whether the five-leafed condition acts as a Mendelian unit character, is a matter that might be of some interest to determine.

Another anomaly consisted of a clover with leaves beautifully colored—variegated in black, brown, crimson, scarlet, yellow, white and green, in different forms and figures, no two plants being closely similar in the coloring of the leaves. This plant was introduced as a new variety, but it did not thrive in the Eastern States and has probably been allowed to die out altogether. I have another stock of this which came from chance seedlings, but in no respect equal to the well-bred type formerly possessed.

One of the clovers found on my Sebastopol

The Root of the Alfalfa

A very prominent characteristic of the alfalfa plant is that it sends down a relatively gigantic root to really astonishing distances in search of water. This specimen is placed beside a twenty-four inch ruler. Note the rugged character of the root, and also the bends in it, which indicate where it was forced to make its way around a stone or some other obstacle.

place has the color intensified to a bright, rich crimson, which has been reproduced exactly from seed. This is probably a species introduced from South America. A very marked tendency to variation is shown by a large number of clovers when brought to California from distant regions.

The Coming of the Alfalfa

Doubtless the most important of the clover importations of recent years is the plant that has become familiar as the alfalfa.

This is a form of clover, of which there are several species and almost innumerable varieties, that is adaptable to relatively arid regions, inasmuch as it sends its roots to a depth of sometimes ten or even fifteen feet in search of moisture and nutriment. Such a plant, once it has attained a fair growth, is almost independent of the rainfall for months together. Moreover, the vigor of root of the alfalfa is duplicated by the complementary growth of its foliage, which develops so rapidly and so persistently that it may be cut three, four, and even five times in the season, depending upon climate.

The enormous productivity of alfalfa, together with its adaptability to arid regions, led to glowing predictions as to the importance of this new forage crop, when it was first introduced a few years ago. In the southwestern part of the country the

predictions have been more than justified, but alfalfa has failed to make its way in the Eastern and Northern States as rapidly as had been expected.

The probable reason for this is that our most common alfalfa was brought from Peru or Bolivia. Had the plant come from Patagonia or Southern Chile instead, or from Russia, its original home, being therefore represented by hardier varieties, it would probably have spread all over the Eastern States and have added vastly to the value of the forage crop everywhere.

But now hardier types of alfalfa are making their way to the North, and even into Canada, and possibly selective breeding may develop races more resistant to frost than any that have hitherto been imported.

A form known as Turkestan alfalfa has lately been introduced that is recommended for its hardiness. When grown side by side with the ordinary alfalfa on my place, it is difficult to distinguish the two plants. But the Turkestan variety may of course have qualities of hardiness that are not revealed in its appearance. There are other strains being grown that are said to be even more hardy.

The alfalfa has so recently been introduced that it has not been extensively experimented upon. There is no plant, however, which can be taken up

Alfalfa Serving a Double Purpose

Alfalfa grown on a levee along the Sacramento River. Besides one of its values as a forage crop, alfalfa in this case is being used as a binder for levee. Plants taken from the scene depicted here have been found to have thrown their roots more than 25 feet through water, and this mass of root forms a network which holds the levee secure. At the right will be seen a cherry orchard which earned a profit of more than $700 per acre in 1914. It will be a surprise to middle western farmers to learn that this reclaimed land along the Sacramento River is so rich that in spite of all the extra expense and in spite of the fact that twenty dollars per acre is assessed to keep up the levees, it still earns net profits of from $500 to $1,000 per acre.

for development to better advantage by the Government than this thrifty and drought-resisting clover. With this plant, as with the cereals, work should be carried out on an extensive scale by the Government, or by some one who has opportunity to test the plants in a broad and comprehensive way.

As already noted, it is useless to develop a small quantity of seed of a new variety, as the practical stock raiser will not be interested in the seed until it can be offered by the ton.

Some Other Clovers

I have received a large number of alfalfas and clovers from the mountains and plains of Chile, and have been struck with the close similarity between some of these and the clovers that have invaded my gardens. Others, however, are individual in appearance and differ markedly from any that I have seen elsewhere.

Among the Chilean clovers that I am testing is one that is a giant in its proportions as to leaves, foliage, growth, and blossoms.

Another of the Chilean clovers has a heart-shaped brown spot on the leaf. The bloom and seed of this variety closely resemble the common burr clover, but the leaves are several times as large as those of that plant.

The burr clover is of peculiar interest because

it produces enormous quantities of seed that fall from the stalks when ripe, and in our dry climate may remain edible for some months.

The plant was at first thought to be a nuisance, but its value in a region where there is no rain for months together soon came to be recognized. To any one who is not acquainted with the burr clover it is matter for astonishment to see a herd of sheep, cattle, or horses, or a drove of hogs pastured in a field where there is not a vestige of green herbage; and yet to note that these animals are well-conditioned and even fat. They feed on the burr clover seed, the pods of which sometimes cover the ground half an inch or more in depth.

The plant itself has withered or disappeared, but the seed-bearing pods furnish a forage crop that has no substitute in this region, although it would probably be of no special value in the East.

The burr clover has a small leaf and small blossoms. It runs and spreads by long, wiry, slender stalks, and does not stand upright, so that it could never be profitably cut for hay, making only a tangle of tough thread-like stalks. Yet its peculiar property of producing an abundant crop of pods makes it in some localities quite as valuable a pasture plant as the common red clover is in the East.

Hairy Vetch in the Open Field

This tangled mass of vegetation suggest the vigor of growth of hairy vetch. The vetches are legumes, and, as elsewhere explained, secure a portion of their nitrogen from the air, with the aid of nitrifying bacilli that colonize their roots. This gives them an advantage that enables them to thrive in close quarters, as here shown.

Neither the crimson clover nor the common red clover is extensively grown on the Pacific Coast. White clover is cultivated for lawns, mostly in combination with blue grass. It will often cover a bare spot under a tree where the blue grass does not thrive.

The Alsika clover is another form that is seldom seen in California, partly perhaps because it does not tend to send its roots deeply into the soil, and hence is not as well adapted to a dry climate as are the alfalfas. On the other hand it thrives on a clay soil, and in regions to which it is adapted it is a valuable product.

There are numerous other species of clover that have as yet been almost neglected by the plant developer, which offer inviting opportunities.

Even without hybridization, plants grown from a given lot of seed will vary greatly. Selection among the most familiar races of clovers would readily result in the development of new varieties that might be of enormous value. The fact that the plant thrives more or less under disadvantageous surroundings has partly accounted, no doubt, for its neglect by the plant developer. But now that year by year there is a growing recognition of the need of intensive cultivation of farm crops, the clovers are sure to come in for a larger share of attention.

The leguminous plants, including the peas and beans as well as the clovers, have long been known to be characterized by the unusual amount of their protein or nitrogenous content.

The Food Value of Clover

This has led the plant physiologist to regard the clovers as having an exceptionally high food value. As compared with timothy grass, for example, clover contains, pound for pound, a very much larger amount of nitrogen. As nitrogenous foods are the muscle-builders, the value of this is obvious.

There has been a tendency in recent years, to be sure, to question whether the nitrogen content has quite the significance that was formerly ascribed to it. It has been pointed out that horses do not need a very large amount of protein foods unless they are exercising actively, and that in this event they usually secure an adequate amount of protein in the grains, chiefly oats, that are fed them.

Cattle that are being fattened may thrive as well on foods that are less rich in protein.

Milch cattle, and growing cattle, on the other hand, need a nitrogenous diet. And, indeed, all along the line, it is not to be denied that a protein food has exceptional nutritive value. It is partly at least with this in mind that the intelligent agri-

The Familiar Sunflower

This giant representative of an extremely common family is deservedly popular, because of its hardiness, luxuriant growth, and the striking appearance of its large flowers. The sunflower will grow in almost any soil, yet nevertheless it responds readily to good treatment. A plant that is thoroughly watered may grow to twice the dimensions of a companion plant only a few feet away that suffers somewhat from thirst. Try the experiment for yourself next season.

culturist mixes clover with the timothy in his pastures and in his hay-field.

At least a partial explanation of the high nitrogen content of the leguminous plants has been furnished by the discovery that these plants have the very unusual capacity to extract nitrogen from the air. Most plants, as we have seen, are quite powerless to take even the most infinitesimal quantity of nitrogen from the air, and would starve to death for lack of nitrogen even while their tissues are perpetually bathed in it—as the tissues of all aerial plants necessarily are—inasmuch as the atmosphere contains nitrogen as its most abundant element.

But the leguminous plants are able to extract nitrogen from the air directly; not, however, with the aid of their leaves or stems, but only by way of the roots, and there only with the aid of the little tubercles that develop under the influence of micro-organisms. It is, indeed, the micro-organism that extracts and fixes nitrogen and makes it assimilable for the plant.

The tissues of the plant itself have no direct share in the work, beyond giving hospitable refuge to the micro-organisms themselves.

The little tubercles that form on the clovers and the allied plants vary in size and shape with the species of plant, although the micro-organisms

A Hybrid Sunflower

This is a very interesting and beautiful hybrid produced by Mr. Burbank by crossing the Russian sunflower with the ordinary variety. It will be seen that the specimen has been induced largely to give up the habit of seed-formation, graceful petals or petal-like appendages taking the place of seeds.

that produce the tubercles and that assist the plant in securing a supply of nitrogen are closely related. There are, however, different groups of micro-organisms that are able to produce the tubercles and help in nitrogen-fixation.

As micro-organisms are not always present in any given soil, it has been found sometimes desirable to inoculate the soil in which various clovers are to be grown.

This may be done by scattering over the field soil from a field in which tubercle-bearing plants of the same species have been grown in the previous year.

It has been clearly demonstrated that such inoculation of the soil may lead to much freer growth of tubercles than would otherwise take place, and to the increased vigor and growth of the clover crop. The use of artificial cultures of nitrifying bacilli has also been recommended. It is necessary, however, to treat the solution in a particular way in order to insure that the micro-organisms may maintain vitality. If they are dried slowly under the usual atmospheric conditions, the microbes die.

It has been found possible to preserve them by rapid drying of pieces of cotton dipped in a solution containing the microbes.

The Department of Agriculture at Washington

Stages of Progress

These pictures illustrate the stages of development of Mr. Burbank's Russian-American sunflower hybrid. It will be seen that the petals or rayflowers gradually invaded the seed-head from circumference toward the center, until finally they completely won the day. In its final stages, the transformed flower bears scant resemblance to its parent.

has experimented with a method of distributing liquid cultures in glass tubes. Special packages of minerals, including phosphate of potassium, sulphate of magnesium, and ammonium phosphate, are sent with the culture tube to make a nutrient medium in which the culture may be developed.

The clover seeds are moistened with this liquid culture, dried rapidly, and sown as quickly as practicable.

Another method is to sprinkle the liquid on a portion of soil and scatter this over the land.

This inoculation of the soil with the nitrogen-fixing microbes constitutes a new departure in agriculture that would have been quite incomprehensible to any one before the day of the modern bacteriologist. But so much has been learned in recent years about the bacteria and their almost universal prevalence and share in the vital activities of animals and plants that the sprinkling of the soil with bacteria seems almost as commonplace a performance as the sowing of seed.

This method, however, is obviously only an accessory to the methods of the plant developer.

It has exceptional interest as illustrating the application of science to the art of agriculture, but it has no direct association with the work of the experimenter who develops plants by hybridizing and selection.

Just how the leguminous plants came to develop this anomalous habit of serving as hosts for the particular types of bacteria that can aid them by the extraction of nitrogen from the air, it is difficult to understand. But the fact that they have developed the habit is of very great importance, because it enables these plants to enrich the nitrogen content of the soil in which they grow, instead of impoverishing it as do other plants.

By turning the clover under with a plow, the farmer is enabled to restore to the soil an equivalent of the nitrogen that was taken from it in a preceding season by other crops.

The importance of this will be obvious to anyone who is aware that nitrogen is an absolute essential as a constituent of a soil on which good crops of any cultivated plant are to be grown, and who further understands that the available supply of nitrogenous salts with which a depleted soil may be restored has until recently been very limited.

Some readers may recall the prediction made not many years ago by the English chemist, Sir William Crookes, to the effect that the world would presently suffer from a nitrogen famine that would greatly reduce the wheat crop, and perhaps subject the entire race to danger of starvation. At that time the chief supply of nitrates came from the nitrate beds of Chile; and it had been estimated

Sunflower Seeds

Here are sunflower seeds, white, black, and variegated. They suggest interesting possibilities for studies of Mendelian heredity, similar to those that can be made by interbreeding varieties of corn having kernels of different colors. Mr. Burbank's recent experiments with the hybrid sunflowers are of no little interest.

that in less than twenty years these beds would be exhausted.

No one then could say just how the need of the agriculturist would subsequently be met.

But the discovery that leguminous plants extract nitrogen from the air gave partial answer.

And almost simultaneoulsy a more complete answer was supplied by scientific workers, headed by the Swedish chemist, Professor Christian Birkeland, in association with a practical engineer, Mr. S. Eyde, who discovered that it is possible to convert atmospheric nitrogen into nitric acid with the aid of electricity.

Another method of fixing atmospheric nitrogen was soon afterward developed in Italy. Thus the inexhaustible sources of the atmosphere were made available. So there is no longer any danger of a nitrogen famine, and the developer of plants no less than the consumer of plant-products may look forward without apprehension, so far as the danger of the starvation of plants for lack of nitrogen is concerned.

But the mechanical processes of nitrogen fixation are necessarily expensive, and the aid of the clovers and their allies will no doubt continue to be sought for a long time to come by the agriculturist who wishes to restore nitrogen to his fields in the most economical manner.

The first crop of clover is usually cut for hay, and a second crop used to turn under in the fall to fertilize the soil. Thus this plant occupies a unique place among farm products. It not only supplies a valuable forage food, but it also helps the farmer to keep his land in a condition of perennial fertility.

—There is nitrogen, worth millions of dollars, in the air over every farm in America—and by the simple process of raising inoculated legumes, we can extract and employ it — not only without expense, but at the same time producing crops of unusual profit.

A Rich Field for Work in the Textile Plants

Improving the Fibers of Flax, Hemp, and Cotton

THE cultivation of flax in America gives a very striking illustration of the extravagance of our agricultural methods.

Something like two and a quarter million acres of land are given over to the cultivation of flax, the harvested product being about twenty-five million bushels of seed. But the stalks of the plants covering this vast acreage are for the most part regarded as waste material, notwithstanding the fact that the fiber of the flax plant is everywhere recognized as the most aristocratic of vegetable textile materials.

Flax fiber, the material from which linen is made, bears somewhat the same relation to cotton fiber that silk bears to wool. Unfortunately, the plant that bears good seed does not make good fiber; although it can be used as a second quality flax, and has been used as stock for paper.

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Flax in America is usually grown for the seed only, as the high cost of labor makes competition with the foreign product difficult.

Contrariwise the hemp plant (*Cannabis sativa*), a plant belonging to the mulberry family and distantly related to the hop, which resembles the flax only in the fact that it produces a tough and resistant fiber that may be used for textile purposes, is cultivated in this country exclusively for the fiber, its seed being almost altogether neglected. Yet the seed of this plant is prized in other countries for its oil, and its neglect here illustrates the same principle of wasteful use of our agricultural resources.

Hemp, however, is not very extensively grown, being chiefly confined to regions of the bluegrass country centering about Kentucky and Tennessee. Its fiber is coarse, and is used chiefly for making cordage and warp for carpets. At best the cultivation of hemp does not constitute an important industry in the general scale of American agriculture.

Cotton For Seed and Fiber

But when we turn to the third textile plant, cotton, we have to do with an industry that ranks second only to the cultivation of Indian corn.

And here there is a story of waste that assumes more significant proportions. For the cotton plant

also produces seeds as well as fiber; and it is only in comparatively recent years that these seeds have been regarded as other than a waste product the handling of which gave great annoyance.

Fortunately, however, this has been changed in recent decades, and the cotton grower now understands that the seed of the plant is a product quite rivaling in importance the coveted fiber itself. Not only does the seed contain an oil that when pressed out makes a very palatable substitute for the oil of the olive, but the residue constitutes cattle food that sells for from fifteen to twenty dollars a ton—a residue that until recently was used only as fuel, until its value for starch was discovered.

So the cotton plant takes high place among producers of commercial seeds, quite aside from its significance as a producer of the most beautiful, useful, and abundant textile fibers.

In the present connection, however, it is the quality of the cotton as a producer of textiles rather than as a producer of seeds that chiefly claims attention.

The importance of the plant as a producer of fiber is too well-known to require extended comment. Suffice it that America now produces not far from three-quarters of the world's total cotton crop, the land devoted to this crop aggregating

more than twenty-five million acres, and the annual yield averaging something like twelve million bales, with a value of much more than half a billion dollars.

It is obvious that a plant that has such commercial importance is one that beckons the plant developer. For even slight improvements, when applied on so magnificent a scale, may have vast significance.

Cultivaton and Improvements

Some very good work has been done in the improvement of the cotton by selection, without the aid of hybridizing.

The cotton plant came originally from the Orient, having been cultivated in India from time immemorial. It belongs to a large family that includes the hybiscus, bearing beautiful flowers, and the vegetable called in the South the Gumbo.

The Egyptian and Peruvian cotton and Sea Island cotton falls into one group and the American upland cotton and India cotton into another. It is doubted, however, whether the wild prototypes of the cultivated species are known.

The newer classifications recognize twenty-four species or sub-species of cotton, including a number of American species that have attained great commercial importance.

The American upland cotton is a perennial

The Flax Plant

In this country, flax is grown quite extensively, but almost exclusively for the seed; the stalks being regarded as waste material. There is opportunity for some one to develop a variety of flax in which the seed will retain its present good qualities, and the stalk will have a textile fiber of the quality so prized in the European plant.

plant, now cultivated as an annual, that had its original home somewhere in the heart of South America, but which has proved adapted to the climate of the North American cotton belt, and is now the chief producer of cotton in America, and hence in the world.

Sea Island cotton is a species indigenous to the West Indies. It is of larger growth than the upland cotton, attaining a height of three to eight feet, and the bolls that contain the cotton fiber are sharp-pointed and characterized by having only three instead of four or five divisions or locks. Sea Island cotton yields less fiber per acre and is more costly to pick and gin than upland cotton. But it commands a higher price. It is grown chiefly on islands, and along the coast of South Carolina and Georgia. It has peculiar value as material for the making of the foundation for automobile tires.

The India cotton and the Egyptian are not grown extensively in this country, although varieties have been introduced and grown by the United States Bureau of Plant Industry for experimental purposes. It is probable that these species will prove valuable when the method of hybridization is applied to the development of new races of cotton modified to meet special needs.

The cotton has a large, attractive flower, and cross-fertilization occurs to a considerable extent

through the agency of bees and other insects. There is no difficulty in hybridizing different species. On the contrary, it is difficult to prevent cross-pollenation where different kinds of cotton grow in the same vicinity. There is danger of contamination of the strain of any particular cotton in this way. But, on the other hand, there is also the possibility of the production of new and important varieties through such crossing.

Improvement Through Selection.

Until very recently, as already intimated, the improvement in cotton has taken place almost or quite exclusively through the selection of seed, without any conscious effort on the part of the grower to pre-determine the characters of the seed by cross-fertilizing the parent plants.

Indeed, until somewhat recently, cotton growers in common with other agriculturists, have been more or less oblivious to the need of care in the selection of seed. And even now, according to so good an authority as Professor Thomas F. Hunt, of the New York College of Agriculture, probably half the cotton seed planted is taken at random from the public gin. Yet the importance of selection has come to be understood in recent years by a good many growers, and the old slipshod methods have been abandoned by such cotton raisers as appreciate the advantages of applying

European Flax Plant

The fiber of the European flax, as is well known, constitutes the material from which linen cloth is made. In this country, the high cost of labor makes it difficult or impossible to produce flax in competition with the foreign material. But possibly an improved variety might be produced, the cultivation of which would be commercially feasible here.

scientific methods to the betterment of their crop.

The method that has produced excellent results is one that has been illustrated over and over in connection with one after another of my experiments in plant development.

It consists essentially in selecting for seed the products of plants that are observed to be more productive than their fellows, and which at the same time produce cotton fiber of superior quality.

With the cotton, as with other plants, it does not at all suffice to select merely the individual bolls that chance, through some nutritional advantage, to grow to large size. It is necessary to consider the plant itself and its total product as well as the average quality of that product. We have seen that, under precisely similar conditions, different individual plants of every species show a more or less wide range of variation as to size and productivity, resistance to disease, and other qualities.

This variation is quite as notable among cotton plants, even of the most fixed varieties, as among most other cultivated plants.

The practical method employed by the most intelligent cotton raisers is to send trusted employes through the fields to select the plants the product of which is to be saved for seed. The seed cotton thus obtained is ginned separately, and

the owner who has taken this trouble is sure to be repaid by the improved average quality of his crop the ensuing season.

The United States Bureau of Industry has published details as to a method of selective breeding that has been practiced for several years by some growers of Sea Island cotton, through which the staple has been increased from 1.75 to 2.5 inches in length. The method requires four years of selection to secure enough seed for general planting.

The first year, five or more plants are selected as the best in the field. It is urged that it is important to take the seed of at least five plants, not merely of one, because an individual plant of fine appearance may fail to transmit its characteristics. Yet my own experience with a wide range of plants would lead me to have much confidence in the progeny of the one best plant in the field.

However, the practical cotton growers have thought that they secured better results by selecting several plants instead of depending on a single one.

The second year, five hundred or more seeds are selected from each plant for the next year's planting. The second year's crop is examined with great care to see whether the desired qualities are being strongly transmitted. If such is the case,

Hemp Plants

Hemp is grown in America chiefly for its coarse fiber, used in making ropes, cordage, and warp for carpet. Its seed is little utilized, although it makes a valuable oil.

several of the best plants are again selected to furnish seed for a new planting. Meantime the seed of the remainder will suffice to plant a patch of about five acres in the third year.

The third year five hundred or more plants will be grown of each of the individual selections, and as many five-acre seed patches to produce seed for general planting as there were individuals of the first year whose progeny was considered worth propagating.

In the fourth year there will be seed for general planting from the five-acre seed patches of the previous year. There will be several five-acre seed patches from the specially selected individuals of the second year; and five hundred or more plants of each of the individual selections.

That is to say, in this fourth year we shall have a general crop of cotton plants all of which are the descendants in the third filial generation of the five plants or thereabouts selected in the first year.

And inasmuch as each successive year the five or so best plants have been selected out to start a new series, the process of betterment will go on indefinitely. The general crop in each successive year will represent the progeny, not of the crop of the preceding year, but a third-generation offshoot from the best plant of an earlier year. And the crop of this year will of course supply five best

plants to become the progenitors of the general crop four years from now.

And this, it will be obvious, is merely the applying of the familiar rules of selection which we have seen illustrated in the production of specialized races of flowers and fruits and vegetables of many types. The only difference is the practical one that, in my experiments, the inferior members of a fraternity are usually destroyed when the best half dozen have been selected for preservation, instead of being preserved for cropping purposes.

This modification obviously in no wise alters the principle, but it is a practical change that is clearly necessary to meet the needs of a cultivator who, while striving to improve his crop, must at the same time take such crop as can be grown year by year, without waiting for the best ultimate product.

Of course there are limits to the amount of development that is possible through such selective breeding.

The plants operated with have certain hereditary limitations, and these are pretty surely fixed by long generations of inbreeding. When these limits are attained by the practical plant developer, through the carrying out of such a system of rotation as that just outlined for a good many

Indian Hemp

The so-called Indian hemp is not a true hemp, but a plant of an altogether different genus. It has not hitherto proved itself of commercial value, but it has qualities that suggest possibilities of development. The experiments in which the plant is being tested in Mr. Burbank's gardens may or may not lead to important results.

years, the best pure types of cotton represented in the strains under investigation will have been isolated, and the experimenter will find it difficult or impossible to make further improvement by the mere process of selection.

Then it will be necessary to introduce the method of hybridizing, to give new vigor to the plants and to produce new segregations and combinations of characters that will be equivalent to the production of new varieties. And for this purpose, as I have already suggested, the mixing of strains of the American cotton with the Oriental ones, and also doubtless, the utilization of some hitherto neglected wild species may be expected, reasoning from analogy, to prove of value.

A beginning is said to have been made by H. H. Webber, through combining the fine, long, strong lint of the Sea Island cotton with the large bolls and productiveness of the upland cotton.

Insect Foes of Cotton

It goes without saying that a highly specialized plant like the cotton, and in particular a plant growing in sub-tropical regions, is subject to the attacks of many insects.

In point of fact, the distinguished entomologist, Dr. L. O. Howard, enumerates no fewer than 465 species of insects that feed upon the cotton plant. But among these there are four that are so pre-

eminent in their destructiveness as to make the ravages of the others seem insignificant. These are the cut worm (*Aletia argillacea*), the cotton worm, the cotton boll-worm (*Heliothis armiger*), and the Mexican cotton boll weevil (*Anthonomus grandis*).

The cutworms are dangerous to the young plants as to other seedlings. The cotton worm may appear in hordes, but has not been especially destructive in recent years. The cotton boll-worm is an insect which, notwithstanding its name, prefers other crops, in particular maize, to cotton, so that the cotton crop may be protected from its aggression by planting a few rows of maize at intervals of twenty-five cotton rows throughout the cotton field.

But the newest and most aggressive of the pests, the cotton boll weevil, is an enemy that is not so easily reckoned with.

This little insect has been known a long time in Mexico as a pest that attacks and destroys the tender portion of the cotton boll itself. But it is only in recent decades that this insect has worked its way northward and into the cotton region of the United States.

It must now be reckoned as one of the most destructive enemies of the cotton plants in the more southerly districts.

The Jute Plant

The jute is a plant comparatively easy of cultivation, and producing a fiber that has commercial value. The great difficulty, is to separate the fiber in such a way as to make it usable. Lack of machinery for doing this effectively has led to the neglect of this plant in America, although it is sometimes grown in the Gulf States. Mr. Burbank has the plant under observation, but it is perhaps of no great avail to develop it unless some one will invent a machine to handle its fiber.

Quite recently, however, an enemy of the boll weevil has been found in Guatemala by Mr. W. F. Cook, the botanist in charge of investigations in tropical agriculture of the Bureau of Plant Industry. This enemy of the boll weevil is described as a large, red-brown, ant-like insect. It is known to the native of Guatemala as the kelep; entomologists describe it as the Guatemala ant, *Ectatomma tuberculatum.*

This insect is described by Mr. Cook as strikingly adapted by structure and instinct for the work of protecting the cotton against the weevils. It has large jaws or mandibles that fit neatly about the weevil and hold it firmly, and a sting that penetrates a vulnerable point in the shelly armor of the weevil. The sting paralyzes the victim, somewhat as wasps paralyze spiders and caterpillars to supply food for their young.

After paralyzing the weevil with the poison injected by the sting, the kelep carries its prey to its subterranean nest, to feed the larvae.

The kelep does not confine its predaceous attacks to the boll weevil but kills also many other insects found upon the cotton, including the larvae of boll worms and leaf worms. It has the curious habit, Mr. Cook tells us, of storing the dismembered skeletons of captured insects in special chambers of its subterranean home.

Cotton in the Field

This picture, unlike nearly all the others in these volumes, was not taken on Mr. Burbank's fields and does not represent his individual work. Santa Rosa does not lie within the cotton belt. Mr. Burbank's advice has more than once been sought, however, by those who are cultivating the plant, and his ideas have been utilized in the development of cotton in distant regions.

Through Mr. Cook's efforts, this enemy of the boll weevil has been introduced. It has shown its ability to breed both in captivity and in the cotton fields of Texas. The insect forms colonies that are said to be even more highly developed than are the colonies of ordinary ants. New colonies are formed by a sub-division of the older communities, as among the honey bees, not by solitary females as is usual among ants.

It is expected that the insects will thrive in the cotton districts, and will serve at least to keep the boll weevil in check, although it is not to be hoped, according to Mr. Cook, that it will altogether banish the pest; inasmuch as the weevils have not been exterminated in Guatemala, although the kelep has there imposed a very important check on their increase.

It is urged, however, that additional protection from the boll weevil must be sought through such development of the cotton plant itself as will make it resistant to the attacks of the insect. The authorities of the Department of Agriculture have observed that in the cotton plants of Guatemala, where the weevil is native, the buds do not always drop off after being penetrated, and that the young bolls continue to develop in spite of the attacks of the weevil.

It was found on examination that such resist-

ance was due to the actual growth of new normal tissue into the cavity eaten out by the weevil larvae, with the result uniformly fatal to the larvae itself. It appears that the larvum in its younger stages subsists entirely on the highly organized food material to be found in the pollen grains of the unopened cotton flower. The new tissue formed by a mere swelling or proliferation from the central column of the flower is watery and innutritious, and may starve the larvum to death even if it does not act as a poison.

Here, then, is a method by which the cotton is able to offer effective resistance to the weevil.

It is suggested that if a variety of cotton could be developed in which the tendency to the growth or proliferation of the new tissue was pronounced, as it is in certain individuals, the weevil might be exterminated. It is considered possible that such a variety may exist at the present time in some parts of tropical America, and that if such a resistant variety can be found, it may be possible to develop the characters in the cultivated plant through selection.

Inasmuch as individual plants show this power of resistance, there should be no difficulty in developing and raising cotton plants in which this resistant quality is a uniform characteristic. The problem is obviously identical in principle with

Cotton Flower and Seed-Head

The function of cotton fiber is, of course, to protect the seed and to facilitate its distribution. But Nature would scarcely have carried the elaboration of the protective fiber to such a length, had she not been aided by man, who has selected generation after generation among the cotton plants for the ones that produced the best quality of fiber, as gaged by his own needs. The flower is here shown at earlier and later stages of development.

numberless other problems of plant development that have been solved in the same way.

And here, also, we may reasonably assume, aid may be secured through the careful cross-polleniz- ing of resistant individuals, even if no resistant species can be found with which to effect hybrid- ization. It is reported that a tree cotton indigenous to southern Mexico is partially resistant to the weevil.

It will be of interest to determine whether the peculiar characteristic as to growth of new tissue that makes the individual cotton plants resistant to the weevil constitutes a unit character that will be transmitted along Mendelian lines, comparable therefore to immunity and susceptibility to rust as revealed in Professor Biffen's experiments with the wheat.

Whether or not such is the case, it may be expected that the cotton plants that show resist- ance will transmit this propensity to some of their offspring. It is obvious that an investigation of the hereditary tendencies of the cotton in this regard, coupled with experiments looking to the improvement of the quality of the fiber itself, should have at once a high degree of interest for the plant developer and the promise of large reward to both grower and consumer.

The geographical location of my experiment

Cotton Boll

The so-called boll represents a stage of development of the cotton flower at which the seed is maturing within protective bracts that have not as yet opened. Subsequently the "boll" bursts open, exposing the cotton fiber. When at the stage of development here shown, the boll is subject to the attack of the boll weevil, which has become a pest in some regions of the South.

farms makes it difficult for me to experiment with so tender a plant.

But I have thought that a somewhat extended account of the work of others in the selective breeding of this plant would be of interest, partly because it suggests such close analogies with numerous experiments already detailed. I would urge upon the attention of plant experimenters who are located within the cotton belt the possibility of applying the principles that we have seen outlined in many hybridizing experiments to the improvement of a plant which, despite the excellence of its product, is by no means perfect.

The fundamental principles of plant development are everywhere the same, and the methods that have been employed at Santa Rosa to perfect flowers and orchard fruits and vegetables may be applied with full confidence to the improvement of the cotton plant.

In my own studies, I have come upon a variety of cotton grown in a far northern climate, that of Corea, for ages, and as it appears to be very much hardier than any cotton heretofore known, I have thought it of peculiar interest. The bolls, though produced abundantly, are small and have a short staple, growing on compact, low-bushing shrubs. This matures at Santa Rosa when other cottons seldom reach even the blossoming stage.

I have sent seed of this to experimenters better located; and this unusually hardy dwarf cotton may yet prove of value for crossbreeding purposes.

—The function of cotton fiber is, of course, to protect the seed and to facilitate its distribution. But Nature would scarcely have carried the elaboration of the protective fiber to such a length, had she not been aided by man, who has selected, generation after generation, among the cotton plants, the ones that produced the best quality of fiber —as gaged by his own needs.

PLANTS WHICH YIELD USEFUL CHEMICAL SUBSTANCES

OBSERVATIONS ON SUGAR-CANE HOPS AND SUGAR-BEETS

AN English physician residing in Trinidad made a casual observation that proved enormously important to the growers of sugar-cane.

The physician observed that in the cane fields there were little grass-like plants coming up here and there. The planters whom he asked about it said that it was "grass", and let the matter go at that. But the physician had a suspicion that each blade of grass was really the shoot of a seedling sugar-cane plant.

As it chanced both the planters and the physician were right. The little shoots were young sugar-cane plants; but of course sugar-cane is itself a giant grass, so there was no mistake.

But the planters had not a suspicion as to what kind of grass the shoots were; so when the physician took some of them up and cultivated them,

and they were seen to develop into stalks of sugar-cane, everyone except the physician himself was greatly surprised.

For it had been supposed that the sugar-cane does not produce seed, and such a thing as a seedling sugar-cane was hitherto unheard of.

The sugar-cane does, in point of fact, belong to that comparatively small company of cultivated plants that have almost totally given up the habit of seed-production. We have seen that the horse-radish is another plant that has similarly stopped producing seeds, and that the common potato has almost abandoned the habit. Comment has been made, also, on the rather extraordinary character of this departure from the most sacred traditions of plant life.

That an organism, whose sole purpose beyond the perpetuation of its own individual existence might be said to be the production of seed, should continue to grow and thrive and yet should totally abandon the habit of seed-production seems altogether anomalous.

The explanation is found, as we have seen, in the fact that man provides means for the propagation of horseradish and sugar-cane by division of roots or by transplantation of cuttings. In the case of the potato, nature herself has provided tubers that take the place of seeds in a measure; and we

Sugar-Cane Tassel

Notwithstanding its elaborate tassel, the sugar cane ordinarily does not bear seed. Indeed, until somewhat recently, it was not known to bear seed at all. By rare exception, however, seed is occasionally formed; and the discovery that certain little grass-like plants in a sugar cane field were really seedlings of the sugar plant led to the development of a new variety with exceptional qualities. Ordinarily the sugar cane is propagated by division.

have seen that there is a curious reciprocal relation between the formation of seeds and the formation of tubers, under certain circumstances.

In certain cases, for example, the growth of the roots of a plant or even of the plant stem may be promoted by the removal of the blossoms.

We saw this illustrated in the case of the huckleberry.

We saw also how the potato that was grafted on the stem of a tomato might grow aerial tubers from the axils of the leaves in the position that would normally be occupied by the flowers—and ultimately by seeds, had not the potato given up the habit of seed production.

Another illustration of the affinity between bulbs and flowers is shown by the onion, which sometimes grows a bulb at the top of its stalk, to perform the function of seeds in storing nutrient matter and at other times divides at the base like many other similar plants to form off-shoots from which the new plant will grow in another season.

But in all these cases nature is substituting one means of reproduction for another, or supplementing one means with another, and the essential purpose of race preservation is not for a moment overlooked.

In the case of the sugar-cane, however, it might almost be said that nature has abandoned the idea

of provision for the multiplication of the species, and has left the matter entirely to man. For in giving up the habit of seed-production, the sugar-cane has developed no complementary habit of bulb production. It is propagated by cuttings, but the agency of man is necessary to place those cuttings under proper conditions for growth.

Left to its own devices, the cane would be likely to give an illustration of race suicide.

Rejuvenation Through Seed Production

All this, however, seems out of harmony with the illustrative case with which we began.

For obviously the Trinidad physician could not have found seedlings of the sugar-cane unless the sugar-cane produces seed. In point of fact, it does produce seed *on rare occasions,* but the habit has been so nearly abandoned that most cultivators of the plant supposed that it had been given up altogether. The Trinidad case, however, shows that Nature has not altogether abandoned the sugar-cane to the good graces of man. She still on occasion stimulates the plant to a revival of its long-forgotten custom. And the benefits that result from such revival will be obvious if we follow a little farther the story of the grass-like seedlings that the physician dug up in the cane-fields of Trinidad.

It appears that one of these seedlings, grown to

Varieties of Sorghum

This hardy cousin of the sugar-cane is tolerably familiar in many regions of the United States. It grows far to the North, and may be cultivated like corn. Its juices differ in chemical composition from those of the sugar cane, and its product is not susceptible of refinement; but it makes an excellent syrup.

maturity, was carried subsequently to the Hawaiian Islands, and there propagated in the usual way, so that in due course sufficient plants were grown from it to be tested as to their qualities of growth and sugar production. And it was soon discovered that the progeny of this seedling constituted virtually a new race of sugar-cane; one that would grow on land so poor that it had been allowed to remain fallow.

The new variety, indeed, would produce more sugar on even the poorest land which had been abandoned, than the ordinary variety produces on the best land.

Being taught by this experience, the growers of sugar-cane paid heed to the seedlings in fields where they appeared, and subsequently raised from seed, and distributed in all countries, new varieties of sugar-cane that have probably increased the sugar production of the world by millions of tons each year.

One could not ask a better object lesson in the possibility of rejuvenating a static race of plants through the growing of seedlings.

I first made experiments with seedling sugar-cane in my own gardens, and when reports of these were made, I received letters from the various sugar-growing regions of the world, asking for further information, and now there are several

well equipped experiment stations engaged in the work of raising and testing sugar-cane seedlings.

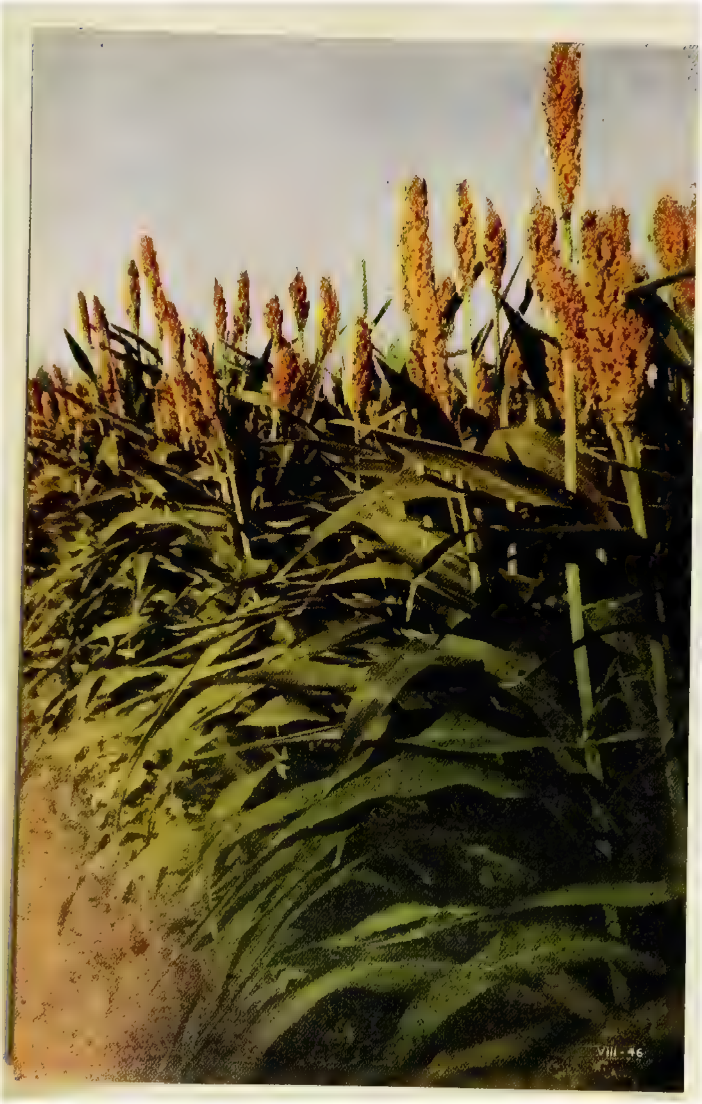
Applying the New Knowledge

The reader will at once recall the case of the Burbank potato, which is in all respects comparable. There, also, a plant that ordinarily does not produce seed was found by exception to be fertile, and the plants grown from the seed showed the widest departure from the form of the parent plant, and constituted the progenitors of a new and improved variety.

The obvious explanation is that the seeds owed their existence to the union of two plant strains, one represented by the pollenate and the other by the pistillate flower, that must necessarily be somewhat divergent. The bringing together of the two racial strains results, as we have seen illustrated over and over, in the giving of renewed vigor or vitality to the off-spring, and in the production of variation through the new assorting and recombination of characters, some of which may have been latent and unrevealed in one or both parents.

In the case of the sugar-cane, propagation by cuttings had been the universal custom with the planters for no one knows how many generations.

As a result, a single cultivated variety of cane that chanced to be in existence when the practice of propagation by cutting was established contin-



Kaffir Corn

In somewhat recent years this thrifty plant has become popular in America as a forage plant. It is of comparatively stunted but rugged growth, and it constitutes a valuable addition to the not very long list of forage plants. It is not grown very extensively, however, in the regular corn belt.

ued unchanged as to its essential characteristics, and there was no apparent opportunity for any modification, except such minor ones as might result from increased or diminished nutrition due to the precise character of the soil and climate.

But the chance finding of the seedlings put the plant on a new basis, and gave the planters new varieties that enabled them to improve the cane, and bring it more in line of competition with the rival sugar-producer that had only recently come into notice, namely the sugar-beet.

At the time when the custom of propagating cane by cuttings was established this plant stood in a class quite by itself as a sugar-producer.

But within the past fifty years the merits of the sugar-beet have come to be understood. The possibility of developing a beet with a high sugar content has been established, and the beet sugar industry has risen to such proportions that it more than rivals the cane industry.

Stimulated by this unexpected competition, which threatened to annihilate the cane sugar industry, somewhat as the work of the synthetic chemist has practically annihilated indigo growing and madder growing, the planters have in recent years given serious attention to the question of the possible improvement of the sugar-producing qualities of the cane.

Several experimenters from different parts of the world have written me concerning this matter within the past fifteen years.

And a number of my friends and acquaintances are now raising sugar-cane from seed in Mexico, the Hawaiian Islands, and Cuba, with an eye to the production of improved varieties. Their efforts should be successful.

Crossbreeding the sugar-cane will give it new vitality, and careful selection from among the new varieties that will appear in the second generation should enable the cultivators to develop new strains of the sugar-bearing cane that will be far richer in their sugar content than any of the old varieties. The cane is at best handicapped in competition with the beet by the fact that it can be grown only in tropical and sub-tropical climates.

If it is to hold its own, it must be developed to its full possibilities of productivity.

Doubtless it will be possible to develop races of sugar-cane having greatly increased size of stalk, and having also a higher percentage of sugar in a given quantity of pulp. In attempting such developments, the experimenters are merely bringing the sugar-cane industry into line with the other great plant industries, most of which were neglected by the scientific plant developer until very recent years.

Broom Corn

Broom corn bears a very close general resemblance to its distant cousin, the familiar corn plant of field and garden; but it has the peculiarity of developing an extremely tough fibrous tassel, furnishing an inimitable material for the making of brooms. The plant would repay cultivation in many regions where it is now neglected.

My own experiments with the cane have not extended beyond the greenhouse, but I have found that the seed germinates readily there, although only a few seeds out of a handful may grow; the contrast in this regard being very striking with the seed of the allied Pampas-grass, which is as diminutive as that of the sugar-cane and not dissimilar in appearance, but which germinates promptly almost to the last seed.

Allies of the Sugar-Cane

I have experimented more extensively with certain relatives of the sugar-cane of the tribe of sorghums.

This includes not only the sorghums that produce the syrups, but also broom-corn, Kaffir corn, and a score or so of allied plants, some of which have great value as fodder plants.

The best known of the sorghums shows its relationship with the sugar-cane in that it produces a syrup which, although not of the same chemical composition as cane sugar, is very sweet and palatable.

Sorghum differs very radically on the other hand from sugar-cane, in that it is a hardy annual plant. It came to us from China but probably originally from South Africa, and it proved adaptable to our soil and climate almost everywhere. It is grown in practically every state in the Union,

for syrup-making. It is known also as a forage plant of very great value, and its stalks supply fodder for the farm animals.

It will be gathered from this that the sorghum is a much less specialized product than the cane, and that it retains its full vigor as a seed producer.

Partly as a result of its cultivation in widely different regions of the globe, and partly no doubt through conscious and unconscious selection on the part of its cultivators, the sorghum has developed many varieties, which are divided into three quite distinct groups.

One type of sorghum is the syrup-producer to which we have just referred.

The other type constitutes a very valuable forage and grain-producing plant, not altogether unlike Indian corn in general appearance, that is almost devoid of sugar.

The third type resembles the others in some respects, but the kernels are smaller and more primitive in form, the plant being used for the manufacture of brooms.

My own work with the sorghums has included a good many different varieties, but has chiefly concerned the non-saccharine types, and, in particular, the one known as broom-corn.

This is a variety of sorghum having long, slender panicles of a specialized form, produced by

Staminate Hop Plant

The flowers of hops are grown on different plants. Only the pistillate flower has value from the standpoint of the hop grower; but it is supposed to be advantageous to have the flowers fertilized, and therefore is customary to grow staminate plants at regular intervals in the hop field. This picture, showing the staminate hop plant, may be contrasted with the succeeding one.

long selection for the special purpose of making brooms and brushes. The product of this plant is familiar in every household, but the plant itself has not been very generally grown in the United States until of late.

There is a vast difference in the different varieties as well as individual plants of broom-corn as regards length, strength, and symmetry of the group of panicle stems, or brush as it is technically called, and equal diversity as to the quantity produced per acre.

My experimental work with the broom-corn has been directed toward the development of a long, and in particular a straight, panicle stem. Most of the broom-corns have long but crooked stems—that is, stems with crooks or crinkles near the base. Moreover, most of the broom-corns under cultivation vary as to the quality of the brush, some of them being long, some short, and there being a corresponding diversity as to color.

I have succeeded, in a few generations of selective breeding, in greatly increasing the number of straight stems of the brush, and giving them a more shapely form. The broom-corn responds readily to selection and care.

My experiments were made by selecting seed from the plant or plants in a lot that showed the best individual characteristics.

Pistillate Hop Plant

The hop is unique among plants having large economic importance in that the only part of it that has value is the flower. The bitter principle, called lupulin, developed in the flower, has great value from the standpoint of the brewer; and hop-growing is an important industry wherever beer is manufactured extensively. It is suggested that selective breeding might improve the quality or enhance the quantity of the essential lupulin borne by the hop flower.

Attention was paid not merely to the brush itself, but also to the stalks of the plant. There is obvious advantage in growing a large, long brush on a dwarfed stalk, that as little plant energy as possible may be used for the production of the stalk, the chief supply being reserved for the more important brush. It was found very difficult, but not impossible, to improve the plant along both lines simultaneously, as it seemed to be working in opposite directions.

I was also able to develop a brush that had improved qualities of firmness and durability, combined with pliable texture.

The syrup-producing sorghums are chiefly of two very closely related types, which are usually spoken of as Amber and Orange sugar-canes.

Individual plants vary a good deal as to their sugar content and other characteristics. My experiments with the syrup-producers have shown that there is a great diversity in the individual plants as to the amount of saccharine substances in their tissues; and that it is possible by careful and systematic selection through successive generations to increase the sugar content, as has been done with the sugar-beet, and is being done with the sugar-cane.

My work, however, has not extended beyond the experimental stages.

I satisfied myself as to the feasibility of the project; it should be carried to completion by some one working under the auspices of the Government or an Agricultural Society where abundant acreage and intelligent help are available.

The work is important, for the syrup-bearing sorghum is a plant of real value, and there is a great demand for its product. But the work of developing the plant does not offer commercial inducements that make it profitable for the private investigator to devote a large amount of time to it.

Some Curious Carbohydrates

The differences between the sweets extracted from the sugar-cane and those taken from the sorghum are very obvious and tangible.

One plant supplies a juice that when boiled and evaporated and refined gives a fine granular product familiar to everyone as sugar.

The juice of the other plant, somewhat similarly treated, constitutes a syrup of varying color, which is exceedingly sweet and palatable, but which cannot be reduced to a granular condition in which it could by any chance be mistaken for cane sugar. Yet the chemist tells us that the sugar content of the juices of these plants is in each case a compound made up exclusively of three elements—carbon, hydrogen, and oxygen—and that the differences observed are due to modi-

A Hop Plant Vista

This view between the rows of hop plants was taken just before the vines were let down for picking. The vines are heavily laden with flowers, and it is necessary to pick these by hand, and just at the right time. Therefore the harvest season is always a busy time in a hop region. There is no mechanical device that gives any assistance to the hand-picker in gathering this crop.

fications in the proportions in which the different elements are compounded.

It appears that sugar of the glucose type, as represented in the syrup of the sorghum, is a much more simple compound than cane sugar.

The Glucose has only 6 atoms of carbon while cane sugar has 18; it has 12 atoms of hydrogen only, whereas cane sugar has 32; and 6 atoms of oxygen, in contrast with the 16 atoms of the cane-sugar molecule.

We have elsewhere seen that starch is a compound of the same elements; differing, indeed, from glucose only in that it has 10 hydrogen atoms instead of 12, and 5 oxygen atoms instead of 6.

Stated in chemical terms, a molecule of starch that has had a molecule of water incorporated with its substance in a chemical union, becomes a molecule of glucose; and, of course, the converse holds —a dehydrated molecule of glucose becomes a molecule of starch.

But to build up a molecule of cane sugar from either starch or glucose requires the introduction and incorporation of many individual atoms, although no new kinds of atoms are required. It is simply that the molecule of cane sugar is a very much more intricate structure, made of the same material. The glucose molecule is, if you will, a

simple dwelling; the cane sugar molecule an elaborate mansion.

But the materials with which they are compounded are precisely the same.

There is a good deal of uncertainty on the part of the chemists as to the exact way in which the various molecules of the different sugars and allied carbohydrate substances are built up.

Some chemists regard a molecule of a substance called methyl aldehyde, which consists of a single atom each of carbon and oxygen combined with two atoms of hydrogen as the basal form of carbon compound which the chlorophyll in the plant leaf makes by bringing together an atom of carbon from the atmosphere and a molecule of water.

From this relatively simple carbon compound more elaborate compounds are built, through the introduction of varying numbers of additional atoms of carbon or hydrogen or oxygen, as the case may be, and all of the intricate juices and flavors and sweet and bitter principles of the various plants are thus compounded in the marvelous laboratory of the plant cell.

The Product of the Hop

Among the multitudes of compounds of the almost endless series in which carbon, hydrogen, and oxygen are joined through the agency of the plant cell, there is one that is of peculiar interest

A Hop Field

This picture, taken earlier in the season, shows the hops before the vines have attained full maturity. They are grown on high poles, with supporting wires or cords, so that the vines may have ample opportunity for growth without interfering with one another. Hop-growing involves work, but the crop is highly profitable.

from the standpoint of the agriculturist, because it gives value to a plant that otherwise would be at best a troublesome weed, to be ignored and despised.

The carbon compound in question is the bitter principle known as lupulin or humulin, which is the really important constituent of the flower of the hop.

This so-called alkaloid, with its exceedingly bitter taste, would never be suspected by any one but a chemist of having the remotest relationship with sugar; yet, in point of fact, it is made of precisely the same elements that make the sweet content of the sugar-cane's delectable juices.

But the three essential elements are differently assorted, as any one might readily surmise who contrasts the bitter taste of the hop with the sweet taste of sugar.

In point of fact, there are 32 atoms of carbon, and 50 atoms of hydrogen, with only 7 atoms of oxygen making up the composition of the alkaloid that gives the hop value. No one knows precisely what is the share of each element in giving any particular quality to a plant product.

The chemist at present can only tear down the molecular structure and tell us of what it is composed.

In the presence of the elaborate carbon

Dried Hops by the Carload

The hop flowers, picked while green, are cured in kilns such as those shown in the frontispiece of the present volume. The dried hops are then stored away for future use or shipped to the markets. They require no treatment beyond drying.

compounds that are represented by such substances as sugar and lupulin, he is like a barbarian standing before a beautiful temple.

The barbarian could tear down the temple, but he could not rebuild it.

Similarly the chemist can tear the carbohydrate molecule to pieces, but he cannot put it together again. He knows how to pull to pieces the molecule of sugar, for example, making it into a simpler form of sugar, but he cannot build up even the simplest form of sugar from elementary atoms, were these ever so freely supplied him.

Carbonic acid is everywhere in the air, and water may be had for the asking.

The chemist knows just how many molecules of water he should take to combine with just so many atoms of the carbon to make a molecule of sugar or a molecule of lupulin.

But he does not know how to go about the task.

His only resort is to appeal to the agriculturist in the field, who deals with living laboratories in which the method of compounding these intricate substances is understood.

If the chemist would have sugar, he must seek it in the product of the cane or sorghum, or beet. If he would have lupulin, he must go to the hop vine, for this plant alone has learned the secret of its production.

So it chances that the ancient calling of the agriculturist is as essential to-day as it has always been; and that it is necessary now as always heretofore to cultivate different varieties of plants in order to gain the diverse products that man needs or desires as food or as aids in the industries.

The particular product that a hop vine grows, and in the production of which it has an absolute monopoly, is used, as everyone is aware, by the brewer in the process of the manufacture of beer.

He has been able to find no product that makes a satisfactory substitute for the bitter principle supplied by the lupulin of the hop.

The particular place in which the hop vine stores this bitter alkaloid, once it has manufactured it, is the curious cone-like leafy seed-case or envelope of the pistillate flower. Without doubt the plant develops this bitter principle and stores it there to give the seeds protection from the depredations of animals. But whatever its purpose, the bitter alkaloid provided by the hop was discovered at an early date to have value for the purposes of the brewer, and the hop vine continues to be grown in large quantities solely for the production of this alkaloid.

The hop vine belongs to that somewhat numerous tribe of plants that grow the pistillate and staminate flowers on different vines. It is

Sugar Beets at the Factory

Within very recent years the beet has supplanted the sugar cane as the chief source of the world's sugar supply. This would have seemed quite incredible to the chemists of a century ago, who declared it impossible to produce sugar from the beets in paying quantities. But the plant breeders of Europe solved the problem of increasing the sugar content of the beet, until now it is one of the most profitable of crops.

only the pistillate flower that is of value to the hop grower. But a few staminate flowers are grown here and there in the field to fertilize the others, the cultivators feeling that the seed which would not otherwise be produced has at least the value of adding weight to the flower heads, and probably it adds lupulin also.

The hop has been grown from prehistoric times, and the exact country of its origin is not known, although it is found growing wild in Colorado and New Mexico in the high mountains where it cannot have escaped from cultivation. But comparatively little has been done in the way of developing it, and there is good opportunity for work in this field.

It goes without saying that different strains of hop vines differ in productivity, and in the amount of lupulin that their flowers secrete, and in the quality of the product. Certain Bavarian hops have lupulin of peculiarly fine flavor, but these are all less productive than the hops grown in America.

Following out the principles of plant development repeatedly presented, it may be assumed that the hop can be improved as to productivity and alkaloid content and the quality of the latter by selection. Presumably improvement could be facilitated by hybridization.

The plant is one that can readily be experi-

A Field of Sugar Beets

The sugar beet has been developed by generations of very careful selection. Careful chemical analyses were made of different beets, and only those having a high sugar content were used as beet parents. By this means it has been found possible to develop races of beets in which the sugar content is more than one-third the total bulk. The abundance of the crop is well illustrated in the picture.

mented with, and it should attract the attention of some one living in a region where this plant is extensively cultivated. It is well to bear in mind the staminate parent, and to test its strain of productivity.

The Sugar-Beet

The possibilities of stimulating a plant to outdo itself in the production of its characteristic carbon compounds are well illustrated by the story of the sugar-beet.

It was not much over a half century ago that the merits of this vegetable as a producer of sugar began to be seriously considered.

The fact that sugar-cane grows only in warm climates, and that here is a hardy plant that may be grown anywhere within the temperate zone, stimulated the older Vilmorin brothers of Paris, France, who had learned that the beet produces a sugar chemical identical with that of the sugar-cane, to make inquiry as to whether it might not be possible to grow the beet on a commercial scale, and extract its sugar in competition with the product of the cane.

For a long time the attempt was not attended with great success. But it was finally demonstrated that the sugar-beet, even in its undeveloped form, could be made available as a supplier of sugar on a commercial scale, and then the attempt began to

be made to develop varieties of beet having a larger sugar content.

It is said that the beets at first used contained only about six per cent of sugar.

But by careful selection through a series of generations it has proved possible to increase the sugar content of the beet, just as the length of fiber of the cotton-boll was increased, merely by paying heed generation after generation to the individual plants that showed the best qualities, and saving the seed of these plants only for the raising of future crops.

Year by year the sugar content of the best varieties of beets was increased until from six per cent it had advanced to twenty per cent, and in the case of some individual beets even to thirty-five per cent; and in a few cases as high as thirty-six per cent has been secured from whole fields of beets in Colorado. This should be a wonderful stimulant to plant developers everywhere.

There is perhaps no other case so widely known or involving such large financial interests in which a corresponding improvement has been made in a commercial plant within recent years.

My own share in this work has been, until quite recently, that of an adviser rather than that of a direct experimenter. Some twenty years ago I was asked by the sugar-beet manufacturers of both

A Sugar Beet Anomaly

This curious development on a sugar beet plant was found in the field of Mr. W. K. Winterhalter. Its precise character and significance have not been very clearly determined. Mr. Burbank has frequently seen a similar phenomenon in connection with the squash vine, but regards it as very unusual among beets. Puzzles like this present themselves now and again to add zest to the work of the plant developer.

Europe and America to take up the improvement of the beet. But while I gladly advised in the matter, and pointed out the lines of development through which further improvement might be expected, was unable to give personal attention to experiments with the beet, owing to the pressure of almost numberless other lines of investigation.

More recently, however, I have experimented with varieties of the beet that were already very greatly improved, working with seeds supplied by prominent beet raisers who had developed their product by combining the qualities of ten or more varieties of Russian, German, French, and English sugar-beets.

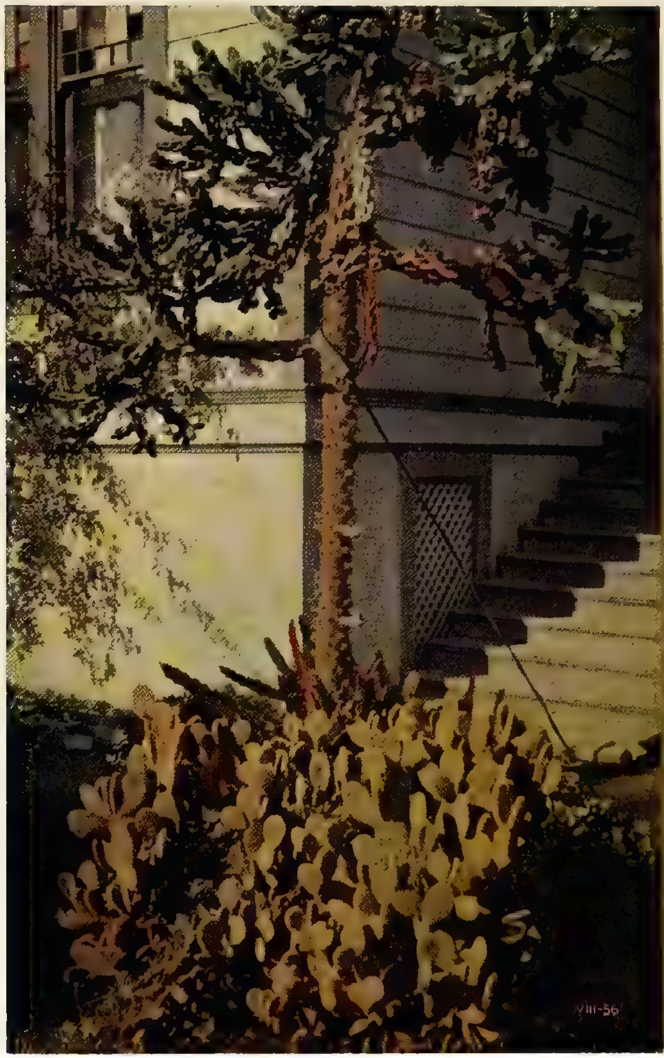
The crossbreeding experiments through which I was endeavoring to increase still further the capacity of the beet for sugar were, for reasons already several times repeated, neglected.

But, so far as they progressed, they fell in line with almost numberless other series of experiments in plant development, and gave promise of the production of a beet that would have a higher sugar content than any beet hitherto under cultivation.

Just what may be the limit to the percentage of sugar that the beet can be expected to develop would be matter of mere conjecture, but that it will represent a considerable advance upon the

percentage already attained is scarcely open to doubt. And even as the case stands, the sugar-beet has attained a position in which it is, as we have already seen, a dangerous rival for the sugar-cane.

—The producers of sugar-beets have been at work while the producers of sugar-cane were sleeping; and the results of their efforts constitute a triumphant demonstration of the value of scientific plant experimentation as an aid to the p r a c t i c a l agriculturist.



The So-Called Candle Cactus

No explanation is required as to how this cactus received its popular name. It is a species oft grown for ornament in regions suited to it. Mr. Burbank has utilized it, along with many others, in his experimental work, although not with directly productive results.

Reclaiming the Deserts With Cactus

The Methods Used to Produce A Spineless Cactus

PLAINSMEN will tell you that in the old days they have known the antelope and the buffalo to come for many miles to feast on cactus plants whose spines had been burnt off by a chance fire.

The spines of the catcus burn like tiny tapers, leaving the slabs nearly unprotected, and the succulent forage thus made accessible constituted a treat that was precisely to the liking of the antelope and the buffalo. Horses and cattle were found to relish the plant equally under the same circumstances.

In the midst of the desert sands, with little else eatable in sight that was more inviting than the sagebrush with its dry and dusty foliage, the succulent cactus slabs, held out invitingly, offered juicy herbage that the animals browsed on with avidity.

Even when the cactus still retained its spines,

the antelope would sometimes try to find a way of getting at its juicy substance. I have heard plainsmen tell of seeing the antelope holding in its mouth a slab that had been dislodged, and twisting its neck this way and that in an effort to find an unprotected spot at which it could nibble.

Obviously the cactus had need of its spines if it was to escape the unwelcome attentions of the browsing animals that found such difficulty in securing sustenance among the dwarfed herbage of the plains and deserts.

But by the same token it appears that if a way could be found to take from the cactus its bristling array of spines, the plant might be made to supply forage in regions where other succulents cannot secure a foothold. So the problem of producing a spineless cactus was one that had but to be suggested to any one who knew the life of the arid regions to make instant appeal.

Materials and Results

It was obvious, however, to anyone having any clear knowledge of plant development, that the task of removing the spines from the cactus would be a very arduous one.

It is true that there are small species of cactus that are spineless, or nearly so, that have been familiar for generations. One of the first pets of my childhood days was a thornless cactus, a beau-

The Quisco Cactus

This is a species from South America which is so thorny that it is impossible to touch the finger to it at any point. Mr. Burbank has given it a place in his garden, along with many others, to see whether it shows a tendency to variation, and thus gives promise of possible modification. It is viewed, however, more as a curiosity than as the probable progenitor of a plant of economic importance.

tiful little plant of the genus *Ephiphlylum.* There are also members of the *Cereus* family that are thornless, showing not a trace of spine on any part of the plant or fruit.

But the cactus plants that are thus unprovided with spines were without exception small and inconspicuous species, and also with a bitter principle so disagreeable that cattle generally refused to eat the plants. So the plants offered no possibilities of direct development through selection, that could promise the production of varieties that would have value as forage plants.

Meantime the large varieties, in particular the members of the genus *Opuntia,* which have peculiarly attractive qualities of size and succulence, are thickly studded with spines for the very reason, doubtless, that were they not thus protected they could never have maintained existence in regions inhabited by the jack rabbit, antelope and buffalo.

If the problem of securing a spineless cactus of value as a forage plant—to reclaim the deserts and supply succulent food for herbivorous animals where now little but sagebrush grows—was to be solved, it would be necessary, I thought, to hybridize the already well-known, partially spineless species of cactus with the large-growing, spiny ones. There seemed reason to hope that a reassortment of hereditary characters might be

brought about, such as we have seen, for example, in the case of thornless blackberry and stoneless plum among other plant developments.

Thus the qualities of size and succulence of the Opuntia might perhaps be combined with the smooth skin of the small, partially spineless species.

The hope that it might be possible to effect such a transformation through hybridization was abundantly justified. In due time such a new race was developed, a gigantic cactus, overtopping all its known ancestors in size, and surpassing them all in succulence of flesh, producing fruit of unpredicted excellence in almost unbelievable quantity, and having a surface as smooth as the palm of your hand. Such a plant was produced as the result of hybridizing experiments, followed up and supplemented by the usual methods of rigid selection. But the result was not achieved with the small cacti referred to. Meantime I was carrying on extensive experiments with all the half-spineless ones which had been well known for centuries.

A Soul-Testing Experience

But the work through which this result was achieved constituted in some respects the most arduous and soul-testing experience that I have ever undergone.

In carrying out the experiments, from the initial

pollenizing through stages that involved the handling of seed and the constant handling of seedlings, I was obliged to associate intimately with the cactus plants, and it was impossible to avoid their spicules. Particularly after the work had advanced to a stage where the larger spines had been removed and the remaining spicules were in little bundles on the older leaves, did it become impossible to handle them without filling one's fingers with the irritating prickles.

For five years or more the cactus blooming season was a period of torment to me both day and night. Time and again I have declared from the bottom of my heart that I wished I had never touched the cactus to attempt to remove its spines. Looking back on the experience now, I feel that I would not have courage to renew the experiments were it necessary to go through the same ordeal again.

Not only would the little spicules find lodgment everywhere in my skin, but my clothing became filled with them, and the little barbs would gradually work their way through the cloth and into my flesh, causing intense irritation.

At first I devoted much time to the endeavor to remove the very inconspicuous but exceedingly irritating and pain-producing little spicules with the aid of a magnifying glass and forceps. But I

Vestigial Leaves

The spine-like projections here shown on the slab of the cactus are vestigial leaves. An account of them, with reference to their evolutionary meaning, is given in Volume I. They are all that remain of the leaves that the cactus once bore; and these reminiscent spikes drop off shortly after coming out.

learned ultimately that the only satisfactory expedient was to shave off the spicules with a sharp razor, or to sandpaper them off, which can readily be done where a great quantity is to be dealt with. When thus reduced in size they would not farther enter the flesh, and gradually the pain would subside.

But the recollection of the torture in connection with the development of the spineless cactus will always remain the most painful one associated with any of my plant developments.

No other complication comparable to this has been encountered in connection with the considerably over ten thousand species of plants with which I have experimented.

But possibly it will appear in the end that no other series of experiments that I have undertaken can be compared in importance to the production of the race of spineless giants which tower to almost treelike proportions, and grow with such rapidity as to produce on good agricultural land from one hundred and fifty to three hundred tons of new forage to the acre annually by the third season after planting, besides nearly one-half as much fruit, yet which are as tender and succulent as grass, affording forage of fine quality in unprecedented quantity, and which can send their roots far into the earth and gain a supply of water

Giants and Dwarfs

These cactus seedlings show amazing variation. Though grown from the same lot of seeds, some of them are mere pigmies, while others rise to proportions that, by contrast, are colossal. The child is father to the man; and the big children of this lot of seedlings will make big mature plants, while the little ones will always be dwarfs.

for their sustenance from subterranean sources in regions where the surface of the country is that of the desert; economizing this for long seasons of drought which may follow.

Hereditary Traits

These new races of spineless cactus are of many varieties, in token of their varied ancestry.

In producing them I followed my usual custom of securing material from every available source.

The main supply came, naturally, from the arid regions of the Southwest; the original home of the cactus. But I received also plants from Minnesota, Montana, Dakota, New England, Missouri, and Colorado, South America, North and South Africa, and regions around the Mediterranean. It could not be known at the outset just what crosses would be most effective, and so experimented on every species on which I could lay hands. I pollenized the giant Tunas with pollen of the little trailing cactus, and with such inconspicuous cousins of the giant as the little hardy *Opuntia vulgaris.*

There were several small more or less spineless species available, and others that produced a comparatively small crop of spines, and of course it was recognized from the outset that these must be our main reliance. Just as the little French partially stoneless plum had been the foundation for building the stoneless plums and prunes of to-day,

it was thought that the little cactus that was smooth skinned might furnish the element of spinelessness in all the future races of spineless cactus, however varied the other elements of their heritage.

The most curious feature about the crossing of the giant Opuntias with the small species, in particular with the little cactus of the Eastern United States known as *Opuntia vulgaris* was that the hybrid was intermediate between the parents as to every characteristic but one. In size, stem, and manner of growth and form of pads, it made a complete blend of the traits of the two totally dissimilar parents.

But its blossom was a relatively enormous flower, very much larger than that of either parent.

As to the blend of traits of this hybrid of giant and dwarf forms of cactus, the phenomena observed were obviously comparable to those that we have seen in sundry other connections. The Primus Berry, the Sunberry, and the Plumcot, will be recalled as illustrating the production of new forms, unlike either parent yet breeding true to the new type in a single generation.

The hybrid between the giant and dwarf Opuntias furnishes another illustration of the same thing. This intermediate type, strikingly dissimilar to either parent yet obviously blending the characteristics of both, bred true to form, showing

Cactus Seedlings Ready For Inspection

Here are some cactus seedlings of very different types, undergoing observation. From among them the ones that show the rudimentary leaves, rather than spines will be selected for further use. They represent a stage in the development of the spineless cactus.

nothing of that tendency to racial variation in the second generation that marks hybrids in general, and that, as will appear in a moment, marks the hybrids of the other cactuses very conspicuously.

But there is an added element of great interest in the fact that the blossoms of the new hybrid so markedly differs from the flowers of either parent and so conspicuously excels either of them in size and beauty.

It would seem that the floral envelope occupies a position in the hereditary scale somewhat different from that of the main stem of the plant. And this is perhaps not strange, when we reflect that the flower is a relatively recent development in the history of plant life.

We have already noted that flowering plants are of comparatively recent origin, geologically speaking.

We have seen evidences here and there of the relative adaptability of the floral envelope as compared with the stem and leaf structure of the plant. So this new illustration of that phenomenon need not surprise us, however much it may interest us.

It would appear, if we may interpret the phenomena just presented, that the giant and dwarf Opuntias have diverged so widely that they are practically at the limits of affinity that permit crossbreeding. The stems and main structures of

the plant, therefore, refuse to conform to the principles of Mendelian segregation, and hit upon a compromise in which the traits of each plant find representation.

But the flower, somewhat less fixed as to its characteristics, and indeed somewhat less widely divergent in the two species, accepts a compromise of a different order, and, under stimulus of that strange influence which we do not well understand but which we see constantly illustrated, it takes on a new vigor of growth.

It surpasses the flowers of either one of its immediate ancestors somewhat as the hybrid Royal Walnut tree surpasses its parents in growth.

This phenomenon of great vigor or tendency to excessive growth developed through hybridization, is, as we have seen, a very common one; its peculiarity in the present instance is merely that here it applies to the flower of the plant alone, whereas elsewhere we have usually seen it apply to the entire structure of the plant, including at least in some cases (for example the Primus Berry, the Phenomenal Berry, and the Royal Walnut) the fruit as well.

Let me add that when the Opuntias not quite so diverse in form as the giants and dwarfs were hybridized, the progeny showed the tendency to increased vigor of general growth, not merely to

Spineless and Spiny of the Same Fraternity

These plants were grown from the seeds of a single cactus fruit. Three of them are perfectly spineless, while one is unusually spiny; but all have the long rounded form of the parent, which differed in this particular from most other plants of the same variety.

increase of the flower, although productivity was also emphasized.

Indeed, it is to the fact of such stimulus of growth by hybridization that my success in developing the gigantic races of spineless cactus is due.

Hybridizing Materials and Methods

The hand pollenizing of the cactus, which was the foundation of these experiments in the producing of the new spineless races, presents no technical difficulties yet requires to be carried out in a particular way.

The cactus flowers open only in the very hottest part of the day, and within fifteen minutes after the pollen-bearers are exposed there is probability that the wind or bees will have accomplished self-fertilization of many of the flowers. It is necessary, therefore, for the experimenter to be on the spot, to anticipate the opening of the flower.

Our method was to collect pollen in watch crystals, and, if necessary, keep it until the flowers we wished to pollenize were matured. As the different varieties of cactus bloom at different seasons, it was sometimes necessary to keep the pollen for a considerable period.

When the plant to be pollenized is ready to bloom, nothing more is necessary than to remove its stamens just before they are matured, and to dust pollen from watch crystal with a camel's hair

Mr. Burbank Selecting Cactus Seedlings

Remember that most of these little fellows are covered with spicules. Mr. Burbank's hands are also covered with spicules; and his clothes are full of them. He asserts that the task of dealing with these tiny citizens, in the effort to educate them into spinelessness, was the most painful one in his experience.

brush over the receptive stigma, being careful not to allow the brush to become smeared with pollen from the stamen, lest the next pollenizing be vitiated.

Each blossom thus pollenized is of course tagged to make permanent record of the cross, in accordance with the method detailed in an earlier chapter.

It was customary, wherever possible, to make the cross reciprocal, although with the Opuntias as with other plants, it appears to make little if any difference as to which is the staminate and which the pistillate parent. Here as elsewhere in the plant world the factors of heredity appear as a rule to be distributed impartially between pollen grains and ovules.

The cactus plants that served as material for my comprehensive experiments aiming at the development of a spineless race of economic value were very numerous as to species and very widely diversified as to form and habit. More than one thousand species of cactus are listed by the botanist, and there is the greatest amount of variability, so that no two botanists are agreed as to the precise classification of all the forms.

Of course I have not had every species of cactus at my disposal, but the number with which I have worked is very large indeed.

For years collectors in all parts of the world have gathered specimens for me, and as knowledge of my work went abroad, even collectors who knew me only by reputation have sent specimens of one kind or another, until my experiment garden may be considered the great gathering place of the varied clans of the cactus family.

In addition to the specimens received from private collectors, I received also a collection that had been gathered at Washington for botanical classification. Most of these were curious thorny specimens, and I think none of them was used in my successful experiments, although all of them were tested.

Some of the most important acquisitions were sent by my friend, David C. Fairchild, including slabs gathered in France and Sicily. I received also specimens from Mexico, South America, and Hawaii, as well as almost numberless varieties from all regions of the United States where any form of cactus grows. The so-called Smith Cactus, a variety introduced into California by Professor Emery E. Smith, about forty years ago, proved of value as a hybridizing agent.

Many Species, but More Names

But it is almost impossible to gain a really accurate conception of the materials employed, because of the great confusion of the classifiers,

How Cactus Plants Are Propagated

Nothing more is necessary than to pat one end of the slab in the ground. Indeed, the slab will probably germinate and send down roots even if it is merely laid on the ground. The cactus is a hardy plant and it takes a lot of rough usage to discourage it. Each of these slabs will grow presently into a large, robust plant.

which has led to the ascribing of different names in many cases to the same species.

For example, the variety which I received under the name "Anacantha" (meaning "without spines") from Fairchild, is identical with specimens received from the Department of Agriculture bearing only a number, and with others received from Italy on one hand, and from my collector in South America on the other, one of the numerous specimens coming under the name "Gymnocarpa."

It was often only by careful inspection and observation under hybridizing experiments that we could identify the various specimens as being of the same species, or same variety.

Again the so-called Morada, another species that proved of value, was first received under the name Amarillo, meaning yellow, from near Vera Cruz, Mexico, it having been sent me by the late Walter Bryant, formerly of Santa Rosa. This I found to be practically identical with another specimen that had come from southern Europe, under the name of Malta.

Another useful variety that came from various regions under different aliases was the form that has been grown in Florida and in California for the last thirty or forty years and which goes by the common name of White Fruit.

There are marked variations in the color and

quality of the fruit of this cactus, the pulp sometimes being white and again variegated with yellow.

Specimens from different parts of the world might at first sight be thought to represent different species or at least different varieties; but I have found the various kinds of fruit growing on contiguous branches of the same plant.

The large species of cactus that grows commonly in the Mediterranean region, known there as Indian Fig or Barbary Fig, is closely similar if not identical with the species called Tuna in Mexico, although the fruit of the Mexican variety is usually somewhat smaller than that of the Old World form. The name tuna is applied indiscriminately in Mexico to cultivated and wild species of the tribe, but the varieties are sometimes recognized by different names, as Tuna Amarillo, Tuna Colorado, Tuna Blanca, etc.

Another quite common Mexican form known as Tapuna, appears to be entitled to recognition as a distinct species of Opuntia.

It produces flat leaves that are generally circular or heart-shaped. The plant does not grow as rapidly as others of the large-fruit Opuntias, and the fruit ripens late in the season. The leaves have a somewhat white appearance, as if dusted with flour, which distinguishes them readily from

Cactus Plants in the Nursery

Here the slabs originally planted have put forth several new slabs, showing that they have taken root and are thriving. The plants here are much too close together for permanent growth. At the end of the first year, the new slabs are used for transplanting at wider distances for forage or fruiting purposes.

the others. The fruit is rarely edible except for stock.

The Tapuna is also of rather exceptional compactness of growth and has high nutritional value as a forage plant. Moreover it is a much hardier species than many others, resisting both cold and wet better than most of the best Opuntias.

So this species has characteristics of obvious value from the standpoint of the plant developer.

The Question of Spinelessness

But what about the matter of spines?

This, of course, from the standpoint of the present investigation, is the vital question.

The question might be answered categorically, with the statement that not a single one of the Opuntias received from any source was altogether spineless. Spineless forms of some of the other genera are familiar, but it was early discovered that the Opuntias must be looked to for the development of a race of cactus that would have economic value. And, as I said, no form of Opuntia was received, among all the hundreds of specimens from various parts of the world, that was altogether spineless and spiculeless.

The form already referred to as the Anacantha, of which specimens were received from Fairchild and from others, came as near to spinelessness as any other form of true Opuntia.

There is a very small and very tender species that is allied to the Opuntias, but is generally classified as a Nopalia, which was received from various parts of California and Mexico, as well as from the Hawaiian Islands, the Philippines, and from Europe, under various names, which is altogether spineless.

But this species is very sensitive to frost or to excessive heat, and in general succumbs to any untoward conditions so readily as to be valueless for this purpose, besides not being relished by any stock.

We have already referred to the fact that there are absolutely spineless forms of the genera *Epiphyllum* and *Cereus*.

These, indeed, have been well known to me for fifty years, and are familiar to all students of plant life. But, as just noted, investigations showed that the genus Opuntia must be depended on for material with which to build an economic race of spineless cactus.

My experiment, it will be understood, was intensely practical in its aim from the outset.

It was not at all my thought merely to produce an interesting race of spineless cactus of diversified forms.

The spineless cactus of my ideal was one that would have practical value as a forage plant; one,

Spineless Cactus Slabs Ready for Shipment

These are selected slabs of some of Mr. Burbank's new spineless varieties of cactus. Simply laid in a tray, and given protection against rough usage, they may be shipped anywhere in the world, practically without regard to the time required. They seem to germinate even better when somewhat thoroughly dry. Such plants as these, for nursery purposes, command a price as high as $5.00 each.

therefore, that would grow luxuriantly in arid places, would be reasonably hardy and resistant to extremes of temperature, and would produce an abundance of succulent forage as well as a supply of palatable fruit.

I repeat that I have still to see a form of Opuntia that is of good size and suitable for forage and yet that is altogether free from spines and spicules, except the ones that have been developed in my experiment gardens, and their progeny; and no such variety has yet been reported, although the authorities of the Agricultural Department of Washington scoured the earth to find such a variety.

These, indeed, are Opuntias fulfilling every specification of spineless forage plants of reasonable hardiness, great adaptability as to soil and easy culture, and enormous productivity; and they are wonderful fruit producers as well. But they are the result of a most arduous series of experiments in plant development, and they constitute new races, entitled to the rank of new species if ordinary botanical standards are to be accepted, that have been developed here, and that, so far as there is any evidence, had never previously existed anywhere in the world.

Their descendants have gone forth to begin the reclamation of the arid places of many lands, and

also to be grown with profit even in the most expensive agricultural lands, especially for feeding with other forage crops. But in no land will they come upon a cactus from any other region that closely resembles them in their combination of entire spinelessness and inviting forage qualities.

Partially Spineless Material

Yet it must be understood that the various specimens of cactus that have been sent me from all over the world, many of which were utilized in crossing and hybridizing and selective experiments, were often forwarded under the supposition that they were specimens of spineless races.

And many of them were *relatively* spineless.

Some of them showed individual slabs that were almost free from spines.

But without exception these plants, notwithstanding their relative smoothness, would be found to have inconspicuous spicules or bristles, which constituted an armament almost as offensive as the larger spines; or else would soon demonstrate that their spinelessness was an individual peculiarity rather than a trait of the race to which they belonged, by developing spines on new slabs.

Yet the fact that partially thornless Opuntias exist in many regions demonstrates a tendency on the part of this plant to give up its spines partially under some circumstances.

Spineless Cactus Showing Two Months' Growth

This picture shows the rapidity of growth of some of Mr. Burbank's improved varieties of spineless cactus. The central slab originally planted has put forth several offshoots, and these of course have sent out numerous branches; so that now, only two months after the time of planting, the plant begins to take on the aspect of a cactus colony. Of course rapid growth was one of the important factors which Mr. Burbank had constantly in mind in making his selections.

It shows that in the heredity of the plant there are strains of spinelessness that might presumably be utilized by the plant developer in the production of a spineless race.

In particular it was learned that there is in the Hawaiian Islands cactus that develops specimens that are partially thornless when grown on mountain sides in positions absolutely inaccessible to browsing animals. Also in California, Mexico, Colorado, New Mexico, and Texas, as I learned from various reports, small patches of half thornless cactus are sometimes found, always in inaccessible crevices among the rocks. These all appear to be species of Nopalia and not Opuntia.

In some of the South Sea Islands where vegetation is abundant, and where browsing animals are few, the Opuntias have either reverted to a spineless condition, or have retained spines that have become merely hairlike appendages.

This tendency to produce partially spineless races when the plant is grown under conditions that make it inaccessible to browsing animals, seems clearly to demonstrate that there are obscure factors of thornlessness in its prehistoric heredity. Our general studies in the effects of hybridizing give adequate clues as to the way in which these submerged factors may be brought to the surface.

A Thrifty Yearling

Here is a year-old plant of one of Mr. Burbank's improved varieties of spineless cactus. So thrifty is this youngster that it will need to be considerably thinned by the removal of numerous slabs, if it is to attain symmetrical growth. But of course each discarded slab may serve as the basal slab of a new plant just like the parent.

The open secret, of course, is to blend the different strains of heredity by hybridizing the various Opuntias, and to select for propagation the seedlings that reveal the spineless condition in combination with other desired qualities.

A Spineless Race Achieved

From the outset I had been making hybridizing experiments, in which I utilized in particular the hardiest races of Opuntias that I could find, choosing, of course, at the same time, those that showed a tendency to produce relatively sparse crops of spines.

In this way I had developed races of cactus that though small in size were hardy, and that ultimately, after nine years' work, produced specimens that were absolutely free from spines. After the spines were gone, however, there remained spicules, which grow in little clusters of several hundred here and there over the surface of the leaf, and which are an even greater annoyance than the larger spines to the plant experimenter, although they are sometimes ignored by browsing beasts. At the present day absolutely smooth ones have been produced on my grounds, bearing also smooth, handsome fruit of excellent quality. As these have come from a stock hardier than any oak tree, they can probably be grown in Alaska.

The hardy and partially spineless cactuses first

A Yearling of Different Type

This is another spineless cactus yearling, but one showing a quite different manner of growth from the one in the preceding picture. Here the slabs are put out symmetrically from the edge of the parent slab, and it may be predicted that the plant will grow into a compact tree-like form, and need little attention.

produced were hybridized, when my more extensive experiments were under way, with the best examples of the large Opuntias received from all parts of the world.

In making these crosses I bore in mind always the condition of relative spinelessness, but also the characteristics of the plant as regards size and fruit-production and quality.

The precise parentage of the hybrids of the first generation was recorded, as already stated. But when the seedlings came to be handled by literal millions, and when the specimens that were utilized numbered scores of alleged species, between which it was often difficult to differentiate, it finally became impossible to attempt to follow the exact pedigrees of the selected plants, if my experiments were to be carried out on the expansive scale that was contemplated.

The seeds from different crosses were planted separately, and the character of the seedling would reveal at an early period the quality of the plant as regards the tendency to produce spines, but not at this early stage the quality or quantity of fruit.

When the cactus seedlings first appear above ground, their cotyledons are spineless. This suggests a period when all cactus plants were without spines, for it is a familiar doctrine that the developing embryo reproduces in epitome the stages of

Another Well-Balanced Cactus

This photograph also shows a spineless cactus in its first season. The manner of growth of this specimen is almost ideal. It spreads its slabs in such a way as to get the largest available supply of light and air for each, without mutual interference. Plants that take this form may be grown relatively close together, insuring a large production per acre.

its racial history; and the plant at the cotyledon stage may be regarded as really still an embryo, inasmuch as it is drawing its nourishment from the nutritive matter stored in the seed.

The first leaf that puts out just above the cotyledons may be spiny or hairy, in recognition of the racial period when spines were worn, even in my new spineless varieties. But the quality of these little spicules will enable the experienced experimenter to determine whether they represent future spines or only a racial reminiscence.

So it is possible to make first selection among the seedlings at a very early period, and to weed out from among the hundreds of thousands all but a few.

Unfortunately the cactus requires from three to five years from the seed to come to fruiting time. So the experimenter who is attempting to develop an improved spineless race must wait patiently throughout this long period before he can effect a second hybridization and thus carry his plant one stage farther along the road to the coveted goal.

But by carefully selecting the seedlings that show the most likelihood of a propensity to produce smooth slabs, yet which at the same time are strong of growth and resistant to unfavorable conditions, it is possible to note marked progress even in a single generation. And when the selected

plants have come to blossoming time and have been hybridized with the best among their fellows, the seedlings of this second generation will show numerous individuals that are markedly superior to their parents or their grandparents in regard to all the desired qualities.

In this second generation (we are not now speaking of the giants and dwarfs referred to earlier in the chapter) is manifested the usual tendency to recombination of the hereditary factors.

In such companies of seedlings as I developed, where hundreds of thousands of plants are grouped together, one is sure to find at least a few specimens that combine the spineless quality of one remote ancestor with the tendency to large growth of another, the fruiting capacity of a third, and so on. By attentive scrutinizing of the seedlings, at an early stage of their development, it was found possible to select thus the few individuals among the thousands that revealed the best combinations of qualities.

These are transplanted by themselves, and given every favorable condition to stimulate their growth and development, and finally placed in long rows for field culture, where they are allowed to stand for three or four years, and in the end, if one out of three hundred or four hundred is found

A Promising Colony

A corner of Mr. Burbank's experimental cactus bed, revealing what has been accomplished in a single season's growth from slabs set out as shown in an earlier picture. Of course these plants are still undergoing observation, and it is clear that they are not all of equal merit. There is none here, however, that has not run the gamut of careful selection.

sufficiently valuable with which to continue the work, the experiment may be considered successful thus far.

It is tedious to wait another term of years before going to the next hybridizing experiment that will give a still better crop of seedlings from which to make new selections. But of course numberless experiments with other plants are being carried out in the interval, and so the time does not seem so long while it is passing, as it seems in retrospect.

Let it suffice that after fifteen years of effort, involving the collection of materials from all over the globe, the hybridizing in the aggregate of thousands of individuals, and successive selections among literal millions of seedlings, I was at last rewarded by the production not merely of one but of numerous varieties of hybrid Opuntias that grow to enormous size, producing an unbelievable quantity of succulent forage; the slabs of which are as free from spines or spicules as a watermelon; and that produce enormous quantities of delicious fruit.

Some inkling, perhaps, of the difficulties of the experiments through which this result was achieved have been revealed in the preceding pages.

Something of the economic importance of the

achievement will be suggested in ensuing chapters. Here let it suffice to repeat that the series of experiments in which the giant spineless fruiting Opuntias were developed was in some respects the most painful, arduous, and difficult of all my long series of plant developments; and that there is reason to believe that its results will ultimately vie with the results of any other single experiment in economic importance.

—Here is a new species of spineless giant cactus which towers to almost tree-like proportions, and grows with such rapidity as to produce, on good agricultural land, from one hundred and fifty to three hundred tons of new forage to the acre annually, by the third season after planting, besides nearly one-half as much fruit.

A Rival of Alfalfa

The Commercial Possibilities of Cactus As Cattle Food

THE right of introduction of certain of the first of my spineless cactus productions in the southern hemisphere was sold to Mr. John M. Rutland, of Australia.

Mr. Rutland had come to Santa Rosa to observe my experiments, and desired to take back with him the Spineless Cactus along with certain other of my new products, including the first of the Plumcots.

He very gladly paid one thousand dollars for a single slab of the most important of the new *Opuntias,* named the "Santa Rosa," and somewhat smaller sums for slabs of several other varieties, including the "Sonoma", "California", "Fresno", and "Chico". He purchased the privilege also of introducing the new plants throughout the southern hemisphere.

This was the first financial return for the work

on the Opuntias. It practically paid for the building of my new home, but, of course, fell far short of the sum expended on the cactus experiments.

A little later a company, formed to control the introduction of the plant in the northern hemisphere, paid me a large sum for my interest in the entire stock, including one or two hardy hybrids that had value for further experimental purposes. The original sale included individual slabs of the different varieties just named, and a few others. The later deliveries included more than fifty tons of slabs and plant bodies, constituting the tangible results of the long series of experiments.

My experiment garden, however, still has a large quantity of Opuntias in various stages of development, but particularly those that are being developed for their fruiting qualities. Not less than five hundred tons of forage—as nearly as can be estimated—are now standing on less than half an acre at Santa Rosa.

As forage plants, the spineless Opuntias already developed have attained a degree of perfection that leaves little to be desired.

Propagation of the Spineless Opuntias

It should be understood that the new varieties of Opuntias, while as a whole they may be regarded as constituting a new species, are individually comparable to the different recognized varie-

The "Gravity" Cactus

This very commendable member of Mr. Burbank's spineless colony has been named the "Gravity." The name was suggested by the fact that many of the slabs tend to assume a perpendicular position, as if they were suspended by invisible wires and under influence of gravity. A plant of this kind grows about the largest possible number of slabs on a given area.

ties of any given orchard fruit, like the best apples, or pears, or plums.

That is to say, they may be indefinitely propagated by division, and all the plants grown from the original individual will retain the essential characteristics of the original. But, like apples, pears, and plums, they cannot be depended on to transmit their best characteristics unvaryingly from the seed.

With the new Opuntias, as with the orchard fruits and so many cultivated plants, the various hereditary factors are blended in more or less unstable combinations, and this unstability will be revealed in the offspring grown from the seed.

So the recognized method of propagating the Opuntias is to plant a slab, and to let this serve as the foundation from which roots and branches will grow. The slabs that develop on each plant may of course be similarly cut off and planted, so that a large territory may be rapidly covered with cactus plants, all precisely like the original.

Mention was made in the preceding chapter of certain cases in which an individual cactus slab that was practically without spines might develop other slabs that would be spiny. This could only occur, however, in case the slab in question was an individual variant which owed its lack of spines to some local condition of altered nutrition.

Contrasting Types of Cactus

At the left, a colony of spineless cactus called the "Tapuna"; at the right a quite different type called the "Tuna." Like all Mr. Burbank's spineless cactuses, these are crossbred seedlings; and they are of closely similar lineage, notwithstanding their widely different appearance. Another instance of the segregation of hereditary characters.

A slab growing as a part of a plant that is spineless throughout will produce only spineless plants, with the exception of very rare bud sports which appear on all plants from time to time.

The case of the Opuntias in this regard is precisely comparable to that of the orchard trees that are propagated by grafting. In each case the entire crop of plants, although multiplied until the offshoots of a single plant may cover hundreds or thousands of acres, really constitutes essentially one plant with divided personality, rather than successive generations of plants.

Spineless Cactus from the Seed

Yet the important question has arisen as to what will take place when the transplanted Opuntias, once they have come to populate the arid places, produce fruit, and scatter their seeds. The answer is that no bad results will ensue.

The reason is that the new hybrid Opuntias have been found to be seedless; or, where the seeds are not entirely eliminated, they are reduced in size and have lost vitality. In my experience, then, when the improved species have ripened and dropped to the ground, under the most favorable possible circumstances, no seedlings have been seen; whereas, when the fruit of the wild ones drops there are abundant seedlings.

The case is comparable to that of the Shasta

A Promising Fruit Crop

This cactus is known as the "Opaline." At the time when the photograph was taken the fruit was only partially matured. It is obvious that a good crop is in prospect. The fruit crop per acre of Mr. Burbank's best fruiting varieties of spineless cactus is measured by scores of tons, instead of by mere bushels.

daisy, which never spreads from the seed, unlike its wild prototype. When the Shasta was first introduced, one of the western states passed a law forbidding its growth in the state. At the present time the Shastas are grown by the millions in that state, as well as in all other regions of the world, and no one has ever complained.

With care in propagating, and reasonable protection, the new spineless Opuntias constitute a race that gives every assurance of permanency.

Yet it should not be forgotten that this race has been developed under conditions of artificial selection, and may need man's protection while it is establishing itself in any given region.

The new spineless Opuntias represent a race that has been permitted, through the fostering influence of artificial selection, to develop, notwithstanding its loss of the protective spines. Now that it has been developed, and the spineless condition combined with the traits of prolific growth and abundant bearing, the race which could never have made its way under natural conditions may be sent back to the desert to provide forage for browsing animals in almost unbelievable quantity.

But even now it will be necessary to protect the young plants from the herds. It is only after the Opuntia has attained a fair growth that it could withstand the attacks of the herbivorous animals,

The Niagara Cactus

It is no easy matter to find appropriate names for new varieties of plants, where so many of them are in evidence as in Mr. Burbank's gardens. Possibly no one recalls just why the present cactus was called the "Niagara,"—conceivably because its slabs tend so to overflow into space and buffet one another.

which find its succulent slabs altogether to their liking.

Some uninformed newspaper reporters have unfortunately given the impression to the public that the seed of the improved varieties could be sown on the desert land like wheat, and grown without fencing or other protection. Let us ask, what crop that man values in any country is not fenced? The more valuable the crop, the more carefully must it be protected. The very fact that all herbivorous animals relish these new creations proves their value and the necessity for protecting them.

Both Food and Drink

So thoroughly appealing, indeed, is the flesh of the cactus plant to the palate of the herbivorous animals that many of them will feed on it even when the slabs are protected by spines.

There are regions in Mexico and Hawaii where the cattle feed habitually on wild species of Opuntias, even though this involves the habitual ingestion of millions of spines and spicules with which the slabs are protected; resulting quite often in sickness or death of the animals.

The manager of a ranch in Hawaii, writing to the editor of the "Butchers' and Stockgrowers' Journal," of California, under date of April 17, 1905, declares that on his ranch there is a paddock

The "Prolific" Cactus

It requires but a glance at the picture to show that this cactus deserves its name. These young plants, only a few months old, are already crowding one another and, as it were, clamoring for space. It will be necessary to transplant them very quickly, or they will constitute an impenetrable jungle.

of 1,200 acres covered very thickly with cactus or prickly pears, with only a slight growth of Bermuda grass. In this paddock, he tells us, are pastured all the year round 400 head of cattle and about 700 hogs.

For both cattle and hogs the cactus furnishes the chief food. The hogs receive only a slight ration of corn, fed to keep them tame, and for the rest live exclusively on the young leaves and fruit of the cactus.

Both cattle and hogs thrive wonderfully. But when the cattle are killed, it is found that the walls of their first stomach are filled with myriads of small spines. The manager adds that he has never known an animal to die from the effects of these spines. This is a half dwarf, partially spineless variety, which is sometimes found in tropical islands. Yet it is obvious that the spines cannot add to the health of the creature, and it is hardly to be doubted that the animals will appreciate the spineless varieties when they have access to them.

But the most remarkable part of the story remains to be told.

This is the fact that the cattle have water to drink only during the rainy season, which usually includes the months of December and January. During these two months there is a certain amount of grass and they have water to drink.

But during the other ten months of the year the cattle subsist exclusively on the fruit and young leaves of the cactus.

They receive not a drop of water except as they find it in the succulent cactus slabs.

"Yet," the narrator continues, "it is a remarkable fact that during the dry months of the year we get a higher percentage of fat cattle from that paddock than from any of the others." He adds that he considers the cattle fed in this way on cactus to make as well-flavored beef as any that he has tasted in San Francisco and New Zealand.

Another record of the same sort is given by Mr. Robert Hind, a millionaire sugar planter and ranchman of Honolulu, who declares that on his ranch in Hawaii he has horses that "do not know what water is and will not drink it if it is brought before them. They have never tasted water."

"I have good, fat cattle," Mr. Hind continues, "that have never seen water and would not know how to act if water touched them. I have other cattle that I have imported from the United States which have not tasted a drop of water since being turned out on my cactus and blue grass pastures. They have lived for years without water, and are as fat as any grass-fed cattle in the United States. They make just as good beef as you can get in any restaurant."

Young "Royal" Cactus Plants

Royal is a word that has attractive meanings when applied to plants, whatever one may think of it nowadays in its application to the human being; and Mr. Burbank would not have given the name to this particular variety of spineless cactus had it not shown altogether exceptional qualities. To casual inspection the most striking thing about it is its propensity to strike out in all directions, as if claiming all the land and air in the neighborhood as its birthright. Perhaps that accounts for its name.

To any one who knows the prime necessity of a water supply for cattle and horses under ordinary conditions of grazing, such statements seem almost incredible. But they are thoroughly authenticated and, indeed, they need excite no surprise in the mind of any one who appreciates the succulent quality of the cactus slab.

In point of fact, the entire cactus plant is a receptacle for holding water.

It was doubtless because the leaves of the cactus transpired water, as do all leaves, that these appendages were given up, so that the cactus of to-day is a leafless plant. A plant that grows in the desert finds it necessary to conserve water. So through natural selection the cactus developed the custom of dropping its leaves when they were only tiny bracts, at the very earliest stage of its growth, developing chlorophyll bodies in its slabs to perform the functions usually performed in the leaf of the plant.

These present a relatively small surface to the air in proportion to their bulk, and conserve in large measure the water that would be transpired from an ordinary leaf system.

This, combined with the habit of the cactus of sending its long, slender roots deep into the soil, accounts for the power of the plant to grow in arid places.

It is not that the cactus can perform its life functions without water any better than can another plant. It is only that the cactus has learned how to seek a water supply in the depths, and to conserve it after it has been found.

What the cactus does then, essentially, is to bring water from the depths of the parched earth, and to store it in its flat slabs, along with nutritious matter, so that these constitute both food and drink for the animal that eats them.

It is obvious that a plant that has such characteristics, now that it has been robbed of the spines that were hitherto its greatest drawback, and quadrupled in productiveness—with a good prospect of increasing it one thousand per cent—constitutes a forage plant that is in a class quite by itself.

The importance of this forage plant is already widely appreciated, but it will be more and more fully understood as the years go by.

Enormous Productivity of the New Opuntias

Not only is the quality of forage produced by the new species of Opuntias of a character to recommend it most highly, but the quantity of forage produced by a given acreage is altogether without precedent. Moreover, being available throughout the year in a succulent form, it is peculiarly valuable for feeding milch cows, producing a greatly increased flow of milk.

The "Banana" Cactus

This variety of of spineless cactus perhaps does not bear a very striking resemblance to the prototype suggested by its name; but, names aside, there is something curiously interesting about the sprangly form it has taken. It solves the problem of cactus architecture by growing horizontal slabs, then adjusting vertical ones along their upper border,—with a few along the lower border for good measure. Carried a few stages farther, this would give the plant the appearance of a modern steel skyscraper in process of construction.

The plants grow rapidly from cutting, and only a few months are required to produce a growth that begins to present forage possibilities.

Of course it will be better to allow the plants to grow for two or three years, and thus attain large size, before slabs are cut away. But after that the new growth may be removed from time to time as required, and the plant will be a constant forage producer for a century at least.

The different varieties of new spineless Opuntias vary a good deal as to size, but all are plants that on good land attain a growth of six or ten feet during a few seasons, and some of them grow much larger.

There is a good deal of difference also as to size and weight of the individual pads or slabs. Many of these weigh eight or nine pounds, although the average is from two to six pounds for the improved varieties. Some of them weigh as high as eighteen to twenty-two pounds, but these are exceptional. But the varieties having largest slabs do not usually produce by any means the greatest amount of food. One of the new varieties of the gigantic Tuna type has produced a slab four and one-half feet in length. This, of course, is something quite out of the ordinary; but slabs from twelve to eighteen inches in length are by no means unusual.

The "Sugar" Cactus

Many of Mr. Burbank's carefully selected spineless varieties have been chosen for their fruiting qualities. Here is one that bears fruit of exceptional sweetness, as its name suggests. The specimens in the foreground, however, had not attained the fruiting age when this picture was taken.

The growth of the plants is so prolific that the total weight of the new slabs grown in a single season, under favorable conditions, has been estimated at almost one hundred tons to the acre. On the best agricultural grounds, as on my own grounds at Santa Rosa, the plants have produced quite five hundred tons per acre in their first four years of growth. This is from some of the most highly improved varieties, on the best of land, but without irrigation or special fertilization.

Of course this growth would not be duplicated on all soils or under all conditions, but even in inferior soils the growth of the Opuntias is phenomenal, and the amount of forage produced each season is greatly in excess of that produced by any other forage plant, not excepting alfalfa.

When the extraordinary weight of fruit that is borne by some varieties is further taken into consideration, it becomes evident that the new spineless Opuntia is the most productive plant ever cultivated. It is within the possibilities that a field of Opuntias, under ideal conditions of cultivation, might yield in new slabs and in fruit an aggregate edible product approximating five hundred tons to the acre. This has already been attained in smaller areas.

As to soil, the Opuntias grow everywhere. They may be planted on rich level land, or on the steep-

The "Signal" Cactus

This variety is characterized by having peculiarly long slender spiked slabs. A glance at almost any of the other pictures will show the distinction. This form is not particularly meritorious; but the variety has been preserved for its other good qualities and for use in future experiments.

est and poorest rocky hillside, along old river-beds, and among rock piles.

But it must not be inferred from this that the plant is oblivious to good treatment. The growth and succulence of the slabs are greatly increased by good soil. Reasonable cultivation of the soil is also of benefit, and, under semi-arid conditions, a very slight irrigation once during the dry season will be highly beneficial, but not absolutely necessary, as the plants will live where not a drop of rain falls for many years, if the soil is not too fiercely sunbaked.

By such treatment, the fruit is greatly increased in size and improved in quality, and the slabs for forage are doubled in weight.

In a word, no plant responds more promptly to good treatment than does the Opuntia.

Yet, on the other hand, the plant retains the primeval capacity of its ancestors to make its way under the most unfavorable conditions.

Making a Forage and Fruit Field

Unlike most other plants, the Opuntias root best during the heat of summer. This is also the best time to transplant them. In fact they should not be moved at other seasons. No one who is familiar with the Opuntias would undertake to root or transplant them during the cold, damp weather, such as would be best for other plants.

The "Hemet" Cactus

Contrast these round, flat, robust slabs with the relatively slender ones shown in the preceding picture. It is obvious that these will produce a far greater yield per acre. Note that the small new slabs are dimpled where the embryo leaves have been. They will be as smooth as their parent slab in due course.

But if transplanted during May, June, July, August, or September they will thrive under almost any treatment. The leaves, blossoms, buds, half grown fruit, or any part of the plant will take root and grow under the most discouraging circumstances. I have seen them develop on the floor back of a cook stove, in the pocket of a winter overcoat, lying on a writing desk, and in similar unlikely places.

The Opuntias differ from nearly all the other plants in that the cuttings must first be wilted before they will grow (unless in the dry, heated part of summer); after which, nothing grows more readily.

When you receive cuttings, place them in some warm, sunny place, and allow them to remain a week or more, after which they will readily form roots and start to grow almost anywhere. They may best be planted so that about one-third of the cutting is below the soil. The cutting may be planted in an upright position, or at any angle—such details make no difference to the Opuntias.

On fairly good soil, to provide a forage field for stock feed, the giant Opuntias should be planted two rows together at intervals of three or four feet, according to variety, and then a space of ten or twelve feet left, and another pair of rows planted in the same way. This has been found to

The "Melrose" Cactus

Here, as in the preceding picture, some of the slabs show the dimpled appearance showing where vestigial leaves recently grew. But old slabs and young alike are absolutely without prickles. You may rub them against your face with impunity.

be the best way to plant the cactus, as by this arrangement space is left for general cultivation and for gathering the crop; otherwise the plants would too completely cover the ground.

The young plants must have protection from marauding beasts. Squirrels and rabbits are particularly fond of the young slabs, and in a country infested by these creatures it may be necessary to fence in a young field of cactus until it attains a considerable growth. Needless to say, it must be protected from the encroachments of farm animals, as they would destroy the young plants utterly.

When the Opuntia attains a reasonable size, it becomes, as already pointed out, a perennial source of forage. The plants live to an indefinite age, and year by year they put out new slabs, which may be cut at any season for feeding purposes.

It is best to cut the forage, and not to give the animals access to the growing plants, as in the latter case they would waste the feed and seriously injure or destroy the plants. The central stems of the old plants, however, attain a woody character that protects them against extermination by stock.

In practical feeding, it is desirable, where possible, to combine the Opuntia slabs with straw,

The "Quillota" Cactus

After inspecting a field like this, one has no hesitancy in accepting the statement that the new growth of slabs and fruit on an acre of perfected Opuntias may amount to 150 tons in a season. It may be questioned whether there is any other type of vegetation that transforms inorganic into organic matter at such an astounding rate.

The "Competent" Cactus

The name "Competent" might be applied with full propriety to almost any of Mr. Burbank's perfected varieties of spineless cactus. If the test of competency be to make one's self at home in any environment, and to grow and thrive and multiply,—in a word, to get on in the world,—then all these opuntias can qualify under the "Competent" banner. But the variety here shown has distinction even in a distinguished company. It has preeminent qualities of "competency" that justify its name.

hay, bran, and other carbonaceous and especially dry foods, like straw, hay, and the like. The Opuntia slabs may be fed as an exclusive diet, and in this case farm animals will have no craving for water. But in fact the cactus is not a complete food, and it is always more economical to feed some dry food with it, alfalfa hay being one of the best, to complete and round it out as a nitrogenous diet.

Almost without exception, herbivorous animals are fond of the cactus. Cattle prefer it to almost any other food, and it makes a superior quality of beef, and exceedingly rich milk, which is not surprising considering the succulence of the cactus and the fact that it contains a relatively large percentage of the salts of sodium, potassium, and magnesium.

A very superior quality of pork is produced from pigs fed on the cactus fruit. The fruit is used also with success as a poultry food. The plant has been fed to horses, which, however, are said as a rule not to relish it until they become accustomed to it.

But the merits of the cactus as a food for animals have too long been recognized to require extended comment. The wild thorny cactus is frequently prepared for stock feeding by burning off its spines, and in Australia the leaves and fruit

The "Special" Cactus

Note the spatulate form of the slabs of this variety of Burbank spineless cactus; also the remarkably compact space-conserving manner of growth. This cactus has no propensity to encroach on the territory of its neighbors; and it may therefore be planted in relatively close rows. The individual slabs are fairly thick and heavy.

The "Robusta" Cactus

Not an inch of waste space here. It would be difficult to mass the slabs more closely together had they been adjusted by hand. In many places they overlap one another like shingles on the roof of a house. Yet the individual slabs are of good size and healthy in appearance, and the plants thrive notwithstanding their scant breathing space.

are boiled to make them available as food for hogs, especially in long seasons of drought. Such facts sufficiently attest the value of this plant, as well as its palatability.

The spines which have hitherto constituted the one perennial drawback having now been removed, and the plant itself having been made to reveal new capacity for growth and for the production of flesh and fruit of peculiar succulence and food value, the cactus, as represented by the new races of spineless Opuntias, must take a leading place among forage plants in all arid and semiarid districts, where the climate is semi-tropical.

—There is no reason why the cactus should not compete on something more than equality with any other forage crop—not excepting alfalfa—even in regions admirably adapted to the growth of plants of less hardy character.

Many Useful Substances in Cactus

The Richness of Its Chemical Content

THE chemical content of the cactus slabs depends largely on the variety and also to a certain extent upon the age of the slabs.

The young shoots in the early period of their growth have a very high water content, as is the case with all succulent herbage. The amount of crude fiber in the leaf at this stage may represent less than one per cent of the total bulk.

On the other hand, the old slabs and the main stalk of the plant take on a growing percentage of woody fiber, which renders them less and less palatable, but which adds to their value from another standpoint, as will appear presently.

The slabs during the period of their best development, when they would ordinarily be used for forage, contain, according to chemical analysis, from 2.71 per cent. to 4.6 per cent. of starch and

its equivalent, with from .58 per cent. to .72 per cent. of protein, and .96 per cent. to 1.68 per cent. of mineral salts. There is also a very small amount of fat, which like the other nutritious elements is being increased in quantity in some of the newer varieties. The varying amount of these food constituents suggests that the quantity may be considerably increased by selection.

Of course the same thing is true of the other constituents. No doubt the protein content, for example, may be increased by selective breeding, just as we have seen done in the case of corn. And in general the constituents of the Opuntia slabs that give them food value may doubtless be increased by careful combination and selection.

Hitherto the development of the plant has been carried along the lines of spinelessness and great size and productivity; although, even as the case stands, there has been a considerable improvement in the percentage of food constituents.

In particular the variety Chico shows such advance upon the other varieties, notably the Santa Rosa, in its percentage of mineral salts as to suggest still greater possibilities of development in this direction, although in some respects the Chico is not an exceptionally good variety. In general the solid content of the Chico variety is 2 per cent. greater than that of the Santa Rosa. Such

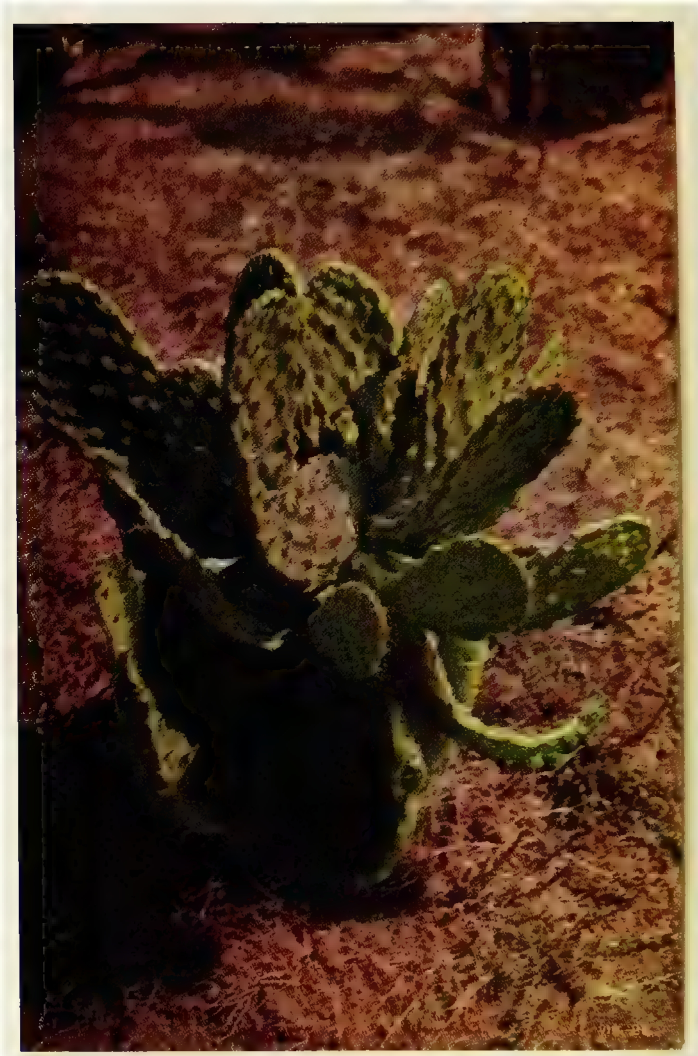
variation is not surprising, but it is sufficient to show that there are possibilities of selection through which the Opuntia is given additional food value.

Even at the present time, however, the slabs of the Opuntias furnish fodder of highly nutritional character. That there is also a high water content is no disadvantage in a plant growing in arid regions. On the contrary, we have seen that this is to be regarded as one of the greatest merits of the plant, inasmuch as it enables animals to secure their water supply by eating the slabs, thus maintaining health and growth even when no drinking water is available for months together.

The qualities of the cactus fruit have been dealt with in an earlier chapter.

It will be recalled that there are numerous varieties of fruit, differing almost as widely as the varieties of apples. The essential character of all the fruits of the improved varieties, however, is a peculiar juiciness of pulp, combined with individuality of flavor and in some cases a slight trace of acid. The fruit of the wild Opuntias has sometimes been characterized as lacking flavor. But constant attention has been paid to the bettering of the fruit and the fruit of the new varieties is popular with all those who are acquainted with it.

On my grounds the choicest varieties of fruits



The "Titania" Cactus

Here is indeed the Sandow of cactuses, struggling manfully under the weight of twenty-nine leaves, the season's outgrowth of a single slab. The parent slab was set out in the Spring, and this picture was taken in August, 1912. Such an infant prodigy deserves its name.

of many kinds are grown, but the workmen usually prefer the fruit of the Opuntias to any other that is in season at this same time.

The improved fruits are rapidly gaining in popularity in the markets. When shipped to the east they bring about the same price as the best oranges, and the fact that they can be produced at a fraction of the cost of growing the orange should give them importance from the standpoint of the orchardist.

Reference has been made also to the fact that the fruit has excellent qualities for making preserves and jams and jellies. The scarlet and crimson varieties have value in supplying coloring matter for other fruit preserves, ices, and confections.

This newer vegetable pigment, with its beautiful shades of color, should largely supplant the objectionable analine dyes that are now so generally used to color ices and confections and non-alcoholic beverages.

The Food Value of the "Leaves"

In countries where the cactus grows abundantly, it has long been known that its young slabs make a palatable form of greens when cooked.

In recent years some scientific experimenters have made the attempt to test the food value of the leaves of the partially improved cactus.

The cactus leaves when fried are a substitute for some of the poorer vegetables. Tender leaves should be selected, the skin peeled off, and the plants fried rapidly in butter. Appetizing preserves may be made from the fruit, somewhat after the manner of apple butter. The fruit itself may be dried and thus preserved for winter use. With the production of 100 tons an acre, there is opportunity to preserve the fruit on a commercial scale, if a sufficient market for it can be developed.

To me it seems that the cooked fruit lacks the fine flavor of the raw fruit. In general the fruit may perhaps be served to best advantage as a salad. But I have on several occasions had jars of delicious jams, made from cactus fruit, sent me from different localities.

The fact that the fruit of the perfected Opuntias contains a high sugar content, amounting sometimes to from 12 to 16 per cent., makes it obvious that this plant might be used for the production of methyl alcohol. The slabs may be used for the same purpose, and the enormous productivity of the plant would make amends for the comparatively low percentage of fermentable starch in its composition.

As a Famine Preventer

It has been estimated that the improved Opuntias produce foliage and fruit so abundantly that

A Remarkable Fruit Colony

Here are forty-three fruits on a single slab of a spineless cactus. It is hardly necessary to state that this is one of Mr. Burbank's highly developed fruiting varieties. The slabs do not often quite duplicate this record, to be sure; but on occasion they even exceed it. A hundred tons to the acre is the possible yield of fruit like this.

they could be grown advantageously on lanu that cost even one thousand dollars per acre.

Analyses made by the Agricultural Department of the State University of California have shown that the new varieties greatly exceed the old ones in nutritive qualities. Yet even the undeveloped Opuntias have long been recognized, particularly by the peoples of the Mediterranean, as having high food value.

The importance of the new plants as suppliers of food for human beings, in regions subject to occasional or habitual shortage, has been recognized by several governments.

The German Government in recent years has tested the new Opuntias at several places in its possessions in Africa.

In parts of India where famines threaten and from time to time destroy millions of people, the spineless cactus is being planted for the purpose of tiding the people over in the years of famine, even if not used as a part of the regular dietary.

The English Government is testing the new plants in Egypt and India.

The plants have been sent to Australia. They are also being tested in Argentina and in other parts of South America.

The new Opuntias differ from almost every other plant, and may be said in a way to resemble

canned food, in that their food content remains in perfect condition on the plants year after year until needed. Nothing more is required than to plant the Opuntias, and fence them against the encroachment of animals. It is not necessary to cultivate them, although it is advantageous during the first two or three years, nor need any attention be paid them until their slabs are needed.

They would thus grow enormously and when the occasion arose they would supply an almost indefinite quantity of food to meet the needs of a population that otherwise must die of starvation.

The value of a plant that need not be cultivated and needs no preparation yet which will perpetually hold in reserve a colossal quantity of food per acre, constantly adding to it (the annual increase being measured in scores or even in hundreds of tons), offers a refuge to populations that are threatened with years of drought and failure of cereal crops that is not duplicated by any other food produced hitherto under cultivation.

Even if the new spineless Opuntias had no other function than this, the time and labor devoted to their production would obviously be repaid a million fold.

Important By-Products

There is one curious property of the slabs of the Opuntias that to some extent militates against

Cactus Patch in Blossom

A glance at this picture will make it clear that the cactus has full claim to consideration as an ornamental plant, and is worthy of a place in any flower garden. It has such important economic uses, as a forage plant and producer of fruit that its flowering qualities are usually overlooked. But they are not likely to be overlooked by any one who has once seen a group of the developed spineless opuntias in blossom in Mr. Burbank's garden.

their popularity as foodstuffs. This is the fact that the leaves contain a mucilaginous substance, the quantity of which, however, varies widely with the different varieties.

The varieties that contain less of the mucilage are used by the Mexicans for the making of confectionery. Some of the finest confections of Mexico are candied cactus leaves.

The leaves also make excellent pickles, the only drawback to which is the presence of the mucilage in the case of some varieties. Those that lack the mucilage make pickles as fine in flavor as the best cucumber pickles.

On the other hand, the mucilage, while undesirable from one standpoint, is not without its value. It may be extracted by cutting the leaves in thin slices, and placing them in water. One or two slabs will make a gallon of good, thick, perfectly transparent mucilage. When this substance dries slowly, it produces a gum that is generally white or of a pearly color, and not easily dissolved in water.

The mucilage is often used locally to mix with whitewash, to which it gives something of the permanency of a paint. It is also used at times for stiffening sleazy cotton goods, and for waterproofing cloth.

Beyond this the economic uses of mucilage

have not been developed. But sooner or later someone will find use for this by-product of the cactus, for the dressing on a large scale of fabrics, or any one of the hundred purposes to which mucilaginous substances are put. I myself have made tentative experiments to test the qualities of the mucilage, but these have not been carried far enough to produce conclusive results.

The Opuntias have possibilities of a quite different character, connected not with their juices or pulp, but with the woody fiber which makes a network in the older leaves, and which comes to form the main substances of the central stalk.

It has been found that this woody network, when the pulp is removed, makes a clean white fiber that is in the most beautiful condition for paper making. The older stems and roots furnish the fiber in considerable quantities, and even the roots are available for the purpose. The amount of paper stock varies much in the different species. The expert estimate of the fiber as a stock for the making of the finest paper, including bank note paper, has been so enthusiastic that it might be well to devote attention to the breeding of some of the spineless Opuntias with an eye to the development of the fiber, so that this by-product of the plant may become of value as a source of paper stock; also for the making of leather board.

A Cactus Patch in Fruit

This picture by no means shows the best that the spineless cactus can do in the way of fruit production. It is selected as representing a fair average. Even at that, the aggregate mass of fruit in this patch of opuntias is enormous. The fruit itself still retains some spicules,—although Mr. Burbank expects to banish these in due course,—but there are no thorns on the slabs to interfere with the gathering of the crop.

One striking peculiarity of the Opuntias fiber is that it is bleached without any preparation. When the pulp is removed, the remaining fiber is perfectly white, and ready for use without necessitating the usual process of bleaching.

So the Opuntia which develops its enormous weight or tonnage of forage and its abundant supply of food for man in the early stages of its growth, will subsequently, without relinquishing its original function, produce supplies of fiber that may be of value. The rapidity and growth of the plant would insure the production of such quantities of material as to give it a certain importance even if it could be grown only on arable lands; but the quantity is at best relatively small.

That it can be grown also on the waste places is obviously an additional merit of the first grade.

A Summary of Qualities

Let us, then, in conclusion summarize briefly the qualities that give the new spineless Opuntias economic value. In so doing I may refer to two or three subordinate uses to which the plants have been put that have not been specifically mentioned in the preceding studies. Here is the list:

First: The new spineless Opuntias supply abundant quantities of fresh fruit that is unique in form and color, of superior flavor, of sure crop, and of good shipping quality. Delicious jams, jellies, and

syrups may be made from the fruits; and its juices are used for coloring ices, jellies, and confectionery.

Second: The slabs or so-called leaves of the plant supply an unprecedented amount of forage for stock of all kinds and for poultry.

Third: The young slabs make excellent pickles, and are a good and wholesome food when fried like the eggplant. They are also boiled and used as greens, and may be prepared with sugar to produce a sweetmeat similar to preserved citron.

Fourth: The leaves are extensively used in Mexico and elsewhere for poultices, and as a substitute for hot water bags—the thornless kind being naturally preferred!

Fifth: The abundant plant juices contain a mucilaginous substance that is used to fix pigments, and which in time will be put to many other important uses.

Sixth: The thorny varieties are used for hedges or fences, as well as for ornament, and even to protect the thornless ones. No animal of any kind will undertake to pass through one of these thorny hedges. In regions subject to the drifting of sand they serve an important purpose as barriers.

Seventh: The fiber of the plant makes an admirable stock for the manufacture of paper, but not as yet in large quantities.

A Young "Eldorado" Cactus Plant

Here is a young plant crowded with tender slabs which, at this stage, are of such consistency that they may be fried and eaten in lieu of a beefsteak, or cut up like cabbage and eaten as a salad. The spineless cactus is being planted extensively in India, with the thought that its slabs and fruit may save the natives from starvation in some year when the grain crops fail.

Eighth: In general, the adaptability of the new Opuntias to the arid regions gives assurance that vast semi-arid regions of the globe will be made habitable and productive, although hitherto they have produced scant if any vegetation of economic value.

Without looking further, it must be clear that a plant having such qualities may be regarded as the most neglected of vegetable products. Owing to its spines, the cactus has been regarded as an enemy of man. Now that its spines are removed its good qualities will in due course be appreciated.

Should their present promise be fulfilled, the giant spineless Opuntias may make vast areas that hitherto have been relatively sterile among the productive regions of the world.

They may supply fodder for unlimited numbers of cattle, that will give cheaper food to the masses, and conspicuously decrease the cost of living.

They may even avert famines in regions that have hitherto accepted the recurrence of starvation years as an inevitable visitation.

And even should the future benefits that accrue from the new spineless Opuntias realize but a fraction of their present promise, these plants might still be entitled to a foremost place among

the forms of vegetable life that have been introduced, or improved, for the service of man within the historical period.

THE HEREDITY OF SPINELESSNESS

Before taking leave of the spineless cactus, it may be of interest to make further inquiry as to the hereditary bearings of the condition of spinelessness.

We have seen that the new spineless opuntias were developed by a long series of experiments in hybridizing and selection, in which use was made of individuals that showed a propensity to depart from the spine-bearing custom of their race. Among the seedlings of these plants, some were found to be much less spiney than others, and it was ultimately possible, by selecting among literal millions of specimens, to develop races absolutely devoid of spines and spicules, as we have seen.

It would not have been unreasonable, perhaps, to expect that the spineless races thus developed would breed true to spinelessness; particularly when we recall that the thornless blackberry, if inbred, produces only thornless progeny. But if such an expectation were entertained, it would be doomed to disappointment, for the spineless cactus does not breed true. In point of fact, there may be found among the seedlings of a spineless variety plants that fairly bristle with spines, rival-

Propagating for Quick Results

Here three slabs of the cactus have been planted together. Each of them will take root, and the production of the new slabs will go ahead with proportionate rapidity. With quick-fruiting in view, such an expedient as this is desirable. The cactus slab takes root equally well whether it is placed on the ground on its side or on the edge, or at either end. It is a hard vegetable to discourage.

ing in this regard the best-protected of their wild ancestors.

Obviously, then, the condition of spinelessness in the cactus has quite different relations in the scheme of heredity from the conditions that govern spinelessness in the blackberry. In the latter case, as we have seen, the spineless condition appears to be recessive, and the thornless individual is as free from tendency to produce thorns as if its entire coterie of ancestors had been perfectly smooth-stemmed. The individual spineless cactus, on the other hand, retains the factors for spines in its germ plasm, to make their influence tangibly felt in a large proportion of the offspring.

Nevertheless, it does not appear that the condition of spininess acts as a simple Mendelian dominant. On the contrary, it appears that the hereditary conditions that govern the spiny condition in the cactus are very complex. The best interpretation would seem to be that there are multitudes of actors for spicules and spines, variously blended in the germ plasm of any given individual. The spiny condition, on the whole, tends to be dominant to the spineless condition, because the spines are a relatively late development in the history of the evolution of the cactus tribe.

But doubtless the period in question was an

exceedingly long one, covering many thousands of cactus generations, during which the plants were becoming better and better protected; and each stage of such development may be thought of as having its hereditary factors in the germ plasm, capable of acting independently.

Thus it is that in the same fraternity some seedlings are exceedingly spiny, while others have a comparatively small number of spines, and a few may be absolutely spineless. Thus, also, is explained the fact, to which attention has been called, that the plants that are altogether spineless may still be provided with minute spicules. Such minute spicules were, perhaps, the first defensive mechanism to be developed in the evolution of the cactus tribe, and they have back of them such numberless generations of heredity that they hold their own with exceptional persistency.

In dealing with the spines and spicules of the cactus, then, we must consider that we have to do not with a single hereditary factor or two, but with a multitude of factors. Now our earlier studies have taught us that where several or many hereditary factors are in question, the probability that they will all be combined in any given way in a single individual decreases at a geometrical ratio. We found, for example, that where ten hereditary factors were under consideration, the probability

Cactus Candy

Here is a tray of really delicious candy made from the cactus. The Mexicans have long been accustomed to make confections from this plant; and now that Mr. Burbank's new fruiting varieties, with their greatly enhanced crops, are available, it may be expected that cactus candy will gain in popularity.

of their combination in a predicted manner was only one in something over a million. In the case of the cactus the factors for spininess doubtless number far more than ten; from which it follows that the probability that any given seedling will have germ plasm absolutely free from any of the factors for spininess is much less than one in a million.

This explains why it was necessary, in our experiments at Santa Rosa, to plant the seeds by literal millions, and to select persistently among uncomputed multitudes of seedlings.

Fortunately the spiny condition reveals itself almost from the outset, so that it was possible to weed out the vast majority of all the seedlings, retaining only, perhaps, a stray dozen or so from among the legions.

As the experiment proceeded, however, it was gratifying to note that in succeeding generations there was an ever-increasing proportion of spineless seedlings. This suggests that some of the factors for spininess were being dropped out of the heredity of the selected plants.

Obviously this seems to augur that should the experiment be carried forward through a sufficient number of generations, the time will probably come when all factors for spininess will have been eliminated from the germ plasm of the

selected opuntias; in which case, they will then breed true to spinelessness from the seed.

This prediction finds further warrant in the fact that the newest races of spineless opuntias show a far more pronounced abhorrence—if the phrase be permitted—of the spiny conditions than did the earlier ones. It was observed that the first spineless opuntias to be developed at Santa Rosa, although remaining perfectly smooth under ordinary conditions of cultivation, had, nevertheless, a tendency to revert to the spiny condition if placed under disadvantageous conditions—say in arid soils, unwatered and uncultivated; a state comparable to that of the wild spiny progenitors.

This tendency to reversion is in itself highly interesting from the standpoint of the student of heredity; being comparable, perhaps, to the observed tendency of some plants, on rare occasions, to form what are termed bud sports. As a rule, plants grown from cuttings or roots or buds reproduce absolutely the characteristics of the parent form. We have seen this illustrated over and over in endless numbers of cases, from orchard fruits to shasta daisies. This rule holds true of the cactus, as has been pointed out in recent chapters. You may produce an entire field of spineless opuntias of any given type, as offshoots of a single slab.

But of course no plant is free from the power

A Cactus-Slab Fan

The fibrous portion of this fan represents the fiber of a cactus leaf from which the pulp has been removed. In the young slab, these fibers are tender and fragile, but they become tense and rigid in the old slabs. An excellent paper may be made from this fiber, and it will doubtless in time be put to many other economic uses.

of environment, and no one needs to be told that the choicest orchard fruits, for example, will fail signally to justify expectations based on observations of their parent forms, unless they are given proper conditions of soil and cultivation. Cuttings or buds of the Baldwin apple, for example, will produce but perverted replicas of the original Baldwin if grown in an arid soil, deprived of moisture, and shaded by other trees. Under such conditions, the choicest varieties of apples tend to revert more or less to the primitive type of the wild ancestor of very remote generations.

Similarly the spineless opuntia may tend to revert to the wild form if placed under primeval conditions. In a stony, arid soil, deprived of moisture, it may not only be stunted in growth, but it may show a propensity to revert to the spiny condition. Such, at any rate, was the case with the earliest spineless opuntias that were produced at Santa Rosa.

As the experiment has gone forward, however, the condition of spininess has been more and more subordinated, as just related; the proof being not only that the individual plants are absolutely free from spines and spicules, but that more and more of their seedlings are found to be spineless. And this elimination of the hereditary factors for spininess is so profound and deep-seated that the newer

Odd Uses of Cactus Spines

Here are needles and a fish-hook made of cactus spines; and a piece of leather with a hole in it put together with cactus needles. It is probable that the aborigines made constant use of the cactus spines for such purposes as these; and the modern Mexicans have not altogether forgotten the customs of their primitive forerunners in this regard.

or more recently developed varieties of spineless opuntias appear to have lost altogether the capacity to revert to the spiny condition. Even under the most adverse conditions of soil and climate, they remain absolutely smooth. One other step of progress, and, we may confidently predict, the factors for spininess will be so completely eliminated from the germ plasm, that the spineless opuntias will breed true from the seeds.

Even then, it must not be expected that the seedlings in any given case will reproduce all the good qualities of the parents; any more than the seedlings of cultivated varieties of apple or pear or peach will duplicate the qualities of their parents. We have seen that the seedlings of the thornless blackberry are not precisely like the parent form. But they all are thornless. Such will be the case, ultimately, with the spineless opuntias.

And it must be obvious that when this condition is attained, the experiment of developing the opuntias in any direction will be greatly facilitated. With many varieties of spineless opuntias in hand, each one absolutely free from the tendency to revert to the spiny condition, we shall be able to carry forward experiments in crossbreeding and selection through which any desired quality may be accentuated and developed.

At the present time, for example, the spineless

opuntias are somewhat lacking in protein content. Their forage value is not quite what it would be if the protein content could be increased. And there is no reason to doubt that such increase may be possible, through selective breeding. Already the developed spineless opuntias exceed all other plants in their capacity to produce an enormous quantity of forage. Through selective breeding their pre-eminence may be still further advanced in that each individual slab may be given enhanced food value. And the quantities of other useful chemical substances in the cactus may similarly be increased in selective varieties.

—Heretofore the development of my cactus has been along the lines of spinelessness, size and productivity; the future will see a marked improvement in the percentage of its food constituents.

A Bundle of Rice

In recent years rice has been introduced into northern California, and is now grown quite extensively in some regions. Not only is it grown in the water, according to the usual custom, but there are also upland varieties that grow like wheat or rye on ordinary soil. It is probable that the production of rice will become an important industry along the Pacific Coast.

Other Useful Plants Which Will Repay Experiment

Transformations and Improvements Waiting to Be Made

A STORY is told that, if true, gives a Mikado of Japan an important place among plant developers.

The Mikado, so the story runs, was riding about the country—as was once the custom—to inspect the crops, and he espied a bunch of rice which seemed to be earlier and more productive than others in the same field.

Evidently aware of one of the fundamental principles of plant breeding, the Mikado directed that the seed from this hill of rice should be carefully preserved and sown by itself the next season. From this seed, if we are to believe the legend, a superior new variety of rice was produced in Japan.

Whatever the authenticity of the story, the fact

that it is told gives evidence that some of the fundamental principles of improvement of plants by selection are widely recognized in the land of the Mikado.

But this, indeed, is a proposition that scarcely needs demonstrating, considering the curious variety of flowers and fruits that have been developed there. That the revered name of the Mikado should be associated in popular legend with the perfecting of the rice, is to be interpreted, I suppose, as an evidence of the importance of this grain to the people of Japan, rather than in any literal sense.

Rice is to the Oriental people what wheat is to the people of the western world, and it is natural that folk-lore should associate the perfecting of this most important of foodstuffs with the most sacred office of the ruler who is regarded as the Father of his people.

Rice and Its Improvement

Mention of the perfecting of special varieties of rice implies the existence of different varieties of this grain.

In point of fact, rice is a variable plant, and one that is therefore susceptible of great improvement. There are many varieties of rice grown in the Orient. There is, for example, a variety that has a very pleasant aroma when cooked. There

A Wild Chilean Grass

This is an unnamed species of grass sent Mr. Burbank by his collector from Chile. Mr. Burbank is experimenting extensively with all manner of grasses, and this specimen will be used in hybridizing tests, with an eye to the possible development of a new forage plant.

are varieties that grow on the upland, the culture of which is similar to that of wheat or barley; notwithstanding the fact that rice is usually thought of as a marsh plant. These have recently been introduced into the cotton regions of the south, and I am told that in some regions they are supplanting the cotton crop. Also an attempt is being made to grow the upland rice in certain sections of northern California, and with a large measure of success.

In point of fact, some botanists have classified no fewer than six species of rice, and there are hundreds of varieties, variation seeming to be no more unusual than with wheat, oats, or barley. It is only the relative unfamiliarity with rice of the western world that has led to the supposition that one kind of rice is like another.

Our estimate of the grain is somewhat analogous to our estimate of the Oriental peoples.

The casual western observer thinks that all Japanese and all Chinamen look a good deal alike; but to the practiced eye there is nearly as great diversity among them as among European races.

The upland rices show their derivation by requiring somewhat moist soil, and they are not grown to advantage in California; at least they have not been extensively cultivated hitherto

except in the moist retentive soils of the Sacramento Valley, and to a certain extent in the Coachella Valley. In the former region, however, the reports as to the growth of the upland rice are exceedingly favorable.

I have tested different kinds of rice here on several occasions, but the results were not such as to induce me to continue its culture, the condition not being favorable.

But the fact that varieties of rice have been developed that grow on the upland gives assurance that further development may be possible in the direction of adapting the plant to general cultivation on lands suitable for growing of other cereals, as already demonstrated in the South. Doubtless a good deal can be done also to make rice a hardier plant through selective breeding; and few attempts at plant development could have greater importance, for rice is a grain not inferior to wheat itself in nutritional value, and one that might be cultivated far more extensively in this country, to very great advantage.

My own experiments have had in view the possibility of the development of the American wild rice of the northern lake regions. This, however, is not a true rice, being classified as Zizania, while rice belongs to the genus Oryza. Some twenty years ago I desired to undertake such an experi-

"Blue-Eyed Grass"

This pleasing cluster represents another of Mr. Burbank's almost numberless proteges of this lowly but interesting tribe. It has greater claims to beauty as a flowering plant than most of its congeners; but of course the qualities for which it is being tested are of a quite different order.

ment, and sent to many places in the United States to get seed of the best varieties. But although I secured seed of the wild rice (it is known to the botanist as *Zizania aquatica*), my experiment, I regret to say, never got beyond the preliminary stages, because the seed would never germinate.

After testing it in successive years I was convinced that the seed of the wild rice must be gathered fresh for planting. For its improvement it would be necessary for men with boats to watch individual plants, and gather seed for immediate planting.

The fact that the plant grows in the water accounts, no doubt, for this unusual quality of the seed, as it will not germinate after once being dried like other grains. It grows always in standing water, and is generally collected by the Indians, who are extremely fond of it. They go out in canoes when the wild rice is ripe, and bending the rice over their canoes thresh it from the heads into the boat. During the last year a well-known San Francisco grain firm collected some of the wild rice and kept it moist, and they expect to make a successful introduction of it in this state. Conceivably a commercial variety of importance might be developed that would be hardier and better adapted to the American climate than the Oriental rice.

I hope even yet to be able to make the experiment. Failing this, I trust that someone else will take the matter in hand.

Some Neglected Grasses

If my work with the rice has been only tentative, there are almost numberless allied grasses with which I have experimented on a comprehensive scale.

Indeed, I have raised, at one time or another during the past thirty-five years, almost every grass that has economic importance, and many never supposed to have value. Among these several fine varieties have been introduced through Cecil Rhodes of South Africa, which proved enormous croppers in moist, warm regions of this state. Some of these I have grown extensively year after year; others only for a single season, for the purpose of obtaining variation in some useful direction.

My work with the familiar giant grasses, Indian corn, sorghum and teosinte, and with the equally familiar small grains, has already been detailed. I refer here to other grasses that are less widely known to the general public, including some that are rarely seen even by the agriculturist.

My experimental work with these various grasses has been as diverse as the qualities of the plants themselves.

A Bed of Land Cress

The cresses are ordinarily grown, as is well known, for their aromatic qualities, and to serve as dainty garnishings, rather than as purveyors of food. Here is a cress that is distinctly ornamental; and is doubly attractive because it grows on land, instead of in the water, as is rather the custom of its tribe. The cresses are a numerous family, and Mr. Burbank has experimented with many of them.

In some cases I have selected for increase of productivity, in others for increase of chemical constituents, or for beauty of plume, or ability to resist drought or frost or wind or moisture; or, again, for compact growing or for ability to spread, or for length and breadth of leaves, or for striping of foliage.

The grasses are so numerous and so diversified that there is opportunity for almost indefinite choice as to lines of development, and there are few other groups of plants that offer greater possibilities.

To casual inspection, to be sure, most of the grasses seem rather uniform, commonplace, or unattractive. They lack the beautiful flowers that so many other plants present, and their forms, if almost universally graceful, are for the most part lacking in picturesqueness. Add that the grasses present great difficulties to the botanical student because of the minuteness of their flowers and the vast number of species more or less closely related, and you may readily understand why this tribe of plants is so commonly neglected by the amateur.

But when we reflect that the family includes the most important producers of food for man and animals; and when we further reflect that there are doubtless many species still undeveloped that might be brought into the company of economic

plants, along with wheat, oats, rye, corn, and rice, it is evident that the grasses should be second to no other form of vegetation in their interest for the plant developer.

Nor will the plants themselves be found to lack interest when once their acquaintance is made in the right way.

They vary in size from tiny sprigs of vegetation to the giant pampas grasses, and to bamboos two hundred feet in height and six inches in diameter. We have already seen that their products comprise not merely universal food and forage for domestic animals, and grains of inestimable value, but juices (in the case of cane and sorghum) that are second in importance only to the grains themselves.

We saw too that there are minor products, such as the panicle of the broom-corn, that have no small measure of usefulness. And it is known to everyone that the stalks and straws of the various grasses have a wide range of utility in the manufacture of numerous articles of everyday use, including the mats beneath our feet and the hats on our heads, as well as the food from the tubers of the nut grass.

Whereas it cannot be said that a family of plants that is thus comprehensively in the service of man — having had, indeed, a most important

Another Unnamed Exotic

This is another of the large group of grasses from Chili, especially collected for Mr. Burbank, most of which have never come under the eye of a classifier, and so are quite unprovided with names. This particular individual grows in a rather compact bunch, and sends up its seed stalks to good height, suggesting possibilities of the making of a good forage plant. It is still undergoing education in Mr. Burbank's gardens.

share in the development of civilization—has failed of recognition, yet it remains true that there are perhaps thousands of grasses that are almost surely susceptible of great improvement, from the human standpoint, to which very little attention has been given by the plant developer.

These present an inviting field for further development.

I shall offer in the succeeding pages suggestions as to a few of them, drawn from my own experiences. To attempt to deal with all the neglected grasses comprehensively, and to point out every individual possibility of useful development, would require volumes rather than paragraphs.

A New Bread-Making Possibility

One of the grasses upon which I worked for several years was what is known in the catalogues as "Idaho Brome-grass," classified as *Bromus inermis*, or *Bromus gigantius*.

I chose this plant on account of its extreme hardiness. It resists drought remarkably, and is very productive. My original seed was received from Montana. I have also grown extensively other species of the same genus, to the number of four or five. My main object was to produce a variety that would yield more forage.

Seeds were sown thinly in boxes in the greenhouse, or in plots out of doors. Selection was

made when the plants were about half an inch high, and before they had put forth their second leaves. At this stage a fairly correct judgment can be formed as to which plants will be rapid growers.

In general, the plant that will ultimately tower above its fellows is found to show superiority in its earliest stages.

By selecting the plants that seem to give most promise, and planting these in rows where the soil is practically the same throughout, it is not difficult to discover the most rapid growers and to weed out the others.

The brome-grasses are much more variable than is commonly supposed even by those who are familiar with them. In point of fact, even within the same species, it is difficult to find two plants that are precisely alike. Some have broad leaves, and some narrow, and the leaves may be variously curled or twisted, as well as variant in color, some being much darker than others.

Some specimens go to seed without producing much foliage; others grow abundant foliage but are tardy of seed-production.

The plants that show this propensity to produce foliage rather than seed are, other things being equal, the ones to select, except from the viewpoint of the seedsman, who does not appreciate

A Bunch of Millets

The millets are a very numerous company, it being estimated that there are at least three hundred species, mostly natives of the tropics. Some of them are cultivated extensively in Europe, but they are not as popular in this country as many other grasses. The species here shown has peculiarly attractive panicles, drooping gracefully with their burden of seeds.

this kind of grass. I have aimed to get a variety with broad, rich, dark green leaves, and found it comparatively easy to develop such a variety. Notwithstanding the great variation shown by the individual bromes, I found that varieties once specialized tend to come somewhat true to type in the next generation.

Therefore it is a very easy matter to improve the different species of bromes.

By far my most interesting experiment with plants of this genus was made about twenty years ago with a plant, seemingly of the species known as *Bromus mollis,* that was found on the edge of the Santa Rosa Creek, about one mile east of Santa Rosa.

This wild grass bore a long head of rather plump seeds that were without awns, and that suggested to my mind the possibility of the development of a commercial grain. The seeds were planted and carefully cultivated, and the best seedlings were selected for propagation, with the result that in the course of a few years a variety was secured in which the size of the seed-head was markedly increased, and in which the individual grains are very much plumper than the original one.

The grain seemed so promising that I tested it by grinding it in a coffee mill. It was found to

produce an excellent flour with a slight yellow tinge.

When prepared and baked in the ordinary way, it made a very good bread.

I was quite sure that a grain of good commercial value could be produced by further selective breeding from the seed of this brome. But I had only a small quantity of seed, and as other matters took my attention I neglected to plant it for two or three seasons; and when it finally was planted it failed to germinate. So the experiment came to an end in unsatisfactory fashion, yet not without offering interesting suggestions as to the possibilities of development of this and other plants of the tribe.

Unfortunately I was not quite sure as to the exact species of brome that furnished the material for this experiment. Moreover, I have not found another plant that showed the same exceptional qualities of seed, with which a new line of investigation might be begun. The one mentioned was discovered only after careful inspection of more than twenty-five thousand examples.

But the finding of one sufficiently proves that there must be others to be found if we search widely enough, so I record the experience as a stimulus to farther search and investigation with a tribe of grasses represented by numerous other

Another Type of Millet

The upright panicles of this millet are strikingly different from the drooping ones shown in the preceding picture. The wide range of variation among the millets makes them peculiarly attractive as plants for the experiments of the would-be developer. Mr. Burbank has various millets among the almost numberless grasses in his colony.

species that are familiar enough in fields and waste places, but which at present are regarded as weeds rather than as friends of the agriculturist.

Some Cultivated Grasses

Some of the most striking results I have ever seen in the way of development of grasses were obtained with the perennial known as the Sweet Vernal Grass (*Anthox anthum*).

This grass is exceedingly variable. A few years ago I raised about fifty thousand plants in boxes. From the seedlings I selected the largest and the smallest; the broad leafed and the narrow; the dark green and the light green; and those showing any other striking peculiarity.

By planting the individuals that presented these diversified traits in plots by themselves, and carefully selecting their seed, races of perennial sweet vernal grass were obtained presenting the widest range of characteristics.

Thus varieties were produced that would bear almost no seed, and others that bore seed abundantly; some which increased from the roots with great rapidity, and others that increased very slowly.

From among the thousands of plants that were raised and scrutinized, I found two or three that would grow more than one hundred times as fast as the smaller ones. Not only was this startling

quality of the fruit of this cactus, the pulp sometimes being white and again variegated with yellow.

Specimens from different parts of the world might at first sight be thought to represent different species or at least different varieties; but I have found the various kinds of fruit growing on contiguous branches of the same plant.

The large species of cactus that grows commonly in the Mediterranean region, known there as Indian Fig or Barbary Fig, is closely similar if not identical with the species called Tuna in Mexico, although the fruit of the Mexican variety is usually somewhat smaller than that of the Old World form. The name tuna is applied indiscriminately in Mexico to cultivated and wild species of the tribe, but the varieties are sometimes recognized by different names, as Tuna Amarillo, Tuna Colorado, Tuna Blanca, etc.

Another quite common Mexican form known as Tapuna, appears to be entitled to recognition as a distinct species of Opuntia.

It produces flat leaves that are generally circular or heart-shaped. The plant does not grow as rapidly as others of the large-fruit Opuntias, and the fruit ripens late in the season. The leaves have a somewhat white appearance, as if dusted with flour, which distinguishes them readily from

Cactus Plants in the Nursery

Here the slabs originally planted have put forth several new slabs, showing that they have taken root and are thriving. The plants here are much too close together for permanent growth. At the end of the first year, the new slabs are used for transplanting at wider distances for forage or fruiting purposes.

Japan Grass

Here is a grass of a still different type, imported by Mr. Burbank from the Orient. The grass experiments are still under way in Mr. Burbank's gardens; but it may confidently be predicted that when the strains of different species from Europe, South America, and Japan are blended, the results will be interesting and notable.

worthy of further attention. In a few more seasons, according to present indications, it will be so fixed as to produce regularly from seed a type of orchard grass that would nearly or often double the growth of the ordinary variety.

Another variable grass that I have cultivated extensively in recent years, for observational purposes rather than commercial varieties, and from which new varieties are being developed, is the species known as *Acrostis fontanesi,* recently introduced from Algeria. From the same plant have been produced seedlings with broad spreading panicles, others with compact spikes, and yet others with beautiful spreading spikes. On sowing seed from different panicles, it was found that the tendency to compactness or looseness of head was transmitted or accentuated, so that widely differing varieties were developed in the second generation from seed of a single plant.

I have obtained some similar results with the Bermuda grass (Capriola), with which I have experimented from time to time during the past twenty years, more particularly in the effort to produce a lawn grass which would fulfil the function in arid regions that the bluegrass fulfils in moist climates.

I have found that this grass varies even more than most others do from seed, and by selection

was able to produce dwarfed varieties, or, on the other hand, the tallest and largest-growing ones; also varieties with broad leaves and others with narrow leaves.

There were plants that came up thickly and made a compact sod, not having the wild running habit of the original variety. And there were others that sent out runners and spread so rapidly that in a single season one plant would cover the ground for ten feet in all directions.

These extraordinary diversities were shown among plants selected from the same lot of seeds. In all there were at least twenty quite distinct varieties developed, each marked by one or more obvious and striking peculiarities.

But as the Bermuda grass is commonly regarded as a weed, none of these were introduced.

Ornamental and Useful Grasses

I have at various times taken great interest in the ornamental grass, commonly known as pampas-grass, the plumes of which were at one time in great demand.

The form of pampas-grass that is most grown in California is that known technically as *Cortaderia argentea.* The plume-like panicles of this grass are familiar ornaments everywhere, and were, in the time of their greatest popularity, articles of some commercial importance.

Australian Rattlesnake Grass

No one who has seen a rattlesnake will need to be told how this grass from Australia received its name. But as the rattlesnake is an American product, it is a question whether the grass bears the same name in its native country. Be that as it may, the seed heads of this curious grass give one the rather disagreeable impression of objects cut from the extremity of a rattlesnake, instead of what they really are. The plant itself is grown as a curiosity rather than for its economic value.

The plumes to be preserved in the best way should not be allowed to come out of the sheath before drying. The long stems, with several leaves attached, are cut just as the tip of the plume begins to show. The leaves are stripped off, and the stalk is placed in the bright sunshine, preferably standing, but more commonly spread on boards or on the ground. Prepared in this way, the panicles do not shake to pieces. They assume the aspect of silky plumes, which are given a peculiar fluffiness and brought to perfection by being placed in a hot oven for a few moments.

I have raised perhaps a hundred thousand seedlings of various pampas-grasses, and have crossed them extensively.

There is no difficulty in effecting cross-fertilization, provided, of course, the two species bloom at the same time. Pollen from the ripe male plant is simply dusted over the pistillate flower. The female plant is the one that is useful for ornament, the male plant having a smaller and coarser plume, which is never silky or fluffy, and which readily falls to pieces under treatment.

There are pampas-grasses, however, that have both staminate and pistillate flowers in the same blossom, and, of course, these cannot be cross-fertilized with such facility.

My most interesting experiments have had to

do with the crossing of a pink variety of pampas-grass that bears both staminate and pistillate flowers, with some of our finest large white varieties. These plants crossed readily and I raised many thousand seedlings. A large proportion of the seedlings were plants bearing both stamens and pistils like the pink parent. Very few were female plants, and therefore bearers of good plumes.

Even when the plumes were produced, they were usually not as large as those of the white parent, and many of them were smaller even than the small plume of the pink parent. This is easily accounted for by the fact that the great white plume has been produced through artificial selection, and therefore its characters were not as well fixed as in the wild type.

An interesting feature of this experiment was that the pink color seemed to appear oftenest on the staminate plants and not on those that bore both stamens and pistils.

This gives a suggestion of the element of sex selection in heredity, which is seldom observed in plants, although common enough among animals. A further evidence of this was seen in the fact that I was never able to fix the color so thoroughly on the female plants as on the male.

The pampas-grass is multiplied by division, so

Water Grass in Bloom

As the number of plants of pleasing appearance that thrive in the water is not very large, this artistic grass with its very attractive clusters of flowers and its sprangly foliage might be thought an acquisition. It has distinctly greater claims to beauty than most members of its tribe.

that there is no difficulty about the multiplication of a new variety. The new varieties do not usually come true from seed. But this is of no importance, inasmuch as a single plant may be so multiplied by division as to produce probably fifty thousand marketable plants, on good soil, in the course of two or three years.

Some Miscellaneous Improvements

From among a great variety of experiments looking to the improvement of farm and forage crops, I will select only three or four additional ones as offering further suggestions.

An interesting anomaly with which I have experimented is a hybrid form of the wild oat.

A field of the second generation of these hybrid oats furnishes one of the most interesting studies of variation that has come under my observation. Inspecting a field of these oats, sown quite thinly, one finds on the same day some that are thoroughly ripe, while others are not yet in bloom. There is corresponding diversity as to the appearance of the plants, some having broad leaves and some narrow ones.

Some of the plants are very tall, and others short and stocky. The panicles are of all forms and sizes. In a word, the hybrids vary in almost every way in which they could vary, and still be recognized as oats.

It is obvious that such a variant type of oats gives opportunity for selection and development of new varieties.

The tendency to vary as to time of ripening has peculiar interest, as suggesting the possibility of adapting oats—and doubtless also the other cereals—to different climates, or even of the production of different varieties in the same locality, which, by ripening at different seasons, would enable the farmer to avoid the excessive rush of work that attends the harvest season.

Several years ago I worked quite extensively on buckwheat. My work consisted largely of selecting the larger, plumper, and lighter-colored kernels. I worked with both the common buckwheat and the Japanese species. A certain amount of crossing was done, but in general the plants were found to be so variable that nothing more was necessary than to select among the different forms that appeared spontaneously.

Considerable, though relatively slow progress was made in the production of a better quality of grain. The experiments were discontinued before I began the extensive hybridization of the two species that had been contemplated. They could without doubt be crossed to advantage.

Among textile plants, and plants of use in the textile industries, my most interesting recent

experiments have had to do with the wild teazel and with the Chilean hemp, that give promise of the production of a valuable fiber.

The teazel, as is well known, has been an important plant, inasmuch as its long hooked burrs are used for producing the nap on cloth, more especially the woolens, and no mechanical device has ever been invented as a thoroughly satisfactory substitute. There are several distinct varieties of the plant, and one of them is a weed that grows along neglected roadsides in California. Among any lot of wild teazels one may find a number of types, and it is not unusually difficult to fix these types by selective breeding.

If it were necessary or desirable for any particular use to make the hooks several times the usual length, or the burrs themselves several times as large, this could easily be accomplished.

My work had to do with some of the peculiar forms rather by way of experiment than with any practical idea. The forms worked with were those with vertical rows of hooks, instead of the spiral ones, and with varieties having extra large hooks at the base and double heads. I carried the experiments forward for several years for my own information and education, and these experiments demonstrated that different kinds of teazel burrs could be developed and fixed if desired.

Pampas Grass

Mr. Burbank has experimented very extensively with various types of pampas grass, developing some interesting varieties, by hybridization and selection. The pampas grasses are not as popular now as they were a few years ago, but they are no less beautiful than they were when they had their heyday of popularity. Here is a cluster that may still be seen on Mr. Burbank's farm at Sebastopol. It is worthy of a place of distinction on any lawn.

Possibly some modified form of teazel may be of use in a future industry. Hitherto it has not been known that modified forms were available.

My experiments with the hemp were conducted largely with an improved Chilean variety, but included also the use of seed from Japan, Russia, and France, as well as from various parts of the United States. The experiments have grown out of a suggestion that I made a number of years ago to a large Boston paper manufacturer, to the effect that it seemed possible that the fiber of the hemp might be used as a substitute for wood pulp in the manufacture of paper.

The experimental work is only at its beginnings, but it seems to be of considerable promise, especially as to improved size of plant, as a hybridized variety has been secured which outgrows all other hemps. The hemp, as is well known, is a dioecious plant, and it may be well to mention the simple but uncommon method of making crosses. All the varieties are first planted separately; and only a few of the largest and tallest male and female plants of each variety are left to bloom. When the heads blossom, the tallest of each variety obtained from different sources are crossed with pollen of the tallest male plants.

After two seasons of this selection and crossing of different strains from different countries, the

varieties were combined by crossing, as before, by selecting the largest and tallest plants, out of which a new race was produced of giant hemp.

I found that a hemp received from China and one from Chile were at first the two tallest and most rapid growers, but they were very shy seed producers in this climate, especially the Chinese one. The variety which I produced from Russia was the most slender, and also the most dwarfed, so this had little to do with the giant hemp which was produced.

Paper made from the fiber of the hemp is found to be of good quality, and although not generally used heretofore must certainly be more prized as other paper pulps become scarce.

I mention this line of investigation here merely to suggest the wide range of opportunities that will open up for the plant developer when he has learned to cooperate with workers in the various industries.

Hitherto we have been prone to take it for granted that all the valuable textile plants have been investigated and perfected. The newer studies suggest that there is still almost boundless opportunity for progress, not only through the improvement of the plants that have been utilized, but also through the introduction of species that have been ignored or neglected.

[END OF VOLUME VIII]

List of Direct Color Photograph Prints in Volume VIII

Clover

Corn

Cotton

Cress

Flax

Grasses

Hemp

Hops

Jute

Millets

Oats

Rice

Rye